HOVERING CRAFT & HYDROFOIL

THE INTERNATIONAL REVIEW OF GROUND EFFECT MACHINES AND HYDROFOILS

KALERGHI-McLEAVY PUBLICATIONS

Volume 1 Number 1
OCTOBER 1961

A SUPRAMAR PT 27 for 50 to 60 passengers. Four of these units were built for Shell Oil Co. by Werf Gusto, Schiedam.

More than 30 units of SUPRAMAR HYDROFOIL BOATS, Schertel/Sachsenberg system, in five different standard models, from 3 to 60 tons, are in regular passenger service in Italy, France, Yugoslavia, Greece, Norway, Sweden, Finland, Egypt, Venezuela, U.S.A., Japan

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Research, Development and Design of Hydrofoil Boats

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SUPRAMAR PT 50 for 100 to 145 passengers. The Cantieri Navali Rodriquez, Messina, have the twelfth boat of this type under construction.

No 1 VOLUME 1

OCTOBER 1961

HOVERING CRAFT & HYDROFOIL

THE INTERNATIONAL REVIEW OF GROUND EFFECT MACHINES & HYDROFOILS

First Hovering Craft & Hydrofoil Monthly in the World

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FIRST COMMERCIAL GEM

Both hydrofoils and air cushion vehicles will have their own individual parts to play in speeding-up overwater transportation. The hydrofoil is now established as being fast and safe for passengers and profitable to the operator, but as yet it is still early days for the GEM. The first fare-paying passenger has still to step aboard one of these craft to make the world's first-ever commercial air cushion trip. Nevertheless, the day that this happens is probably not far off. According to the Chief of the U.S. Navy's Bureau of Ships, the question of whether a 2,000-ton seagoing craft is practical or not is not likely to be answered for another year or so. But certainly the first generation of commercial GEMs is almost with us. Though the art has still a long way to go and the majority of the craft are small, there is nothing of the "flying front porch" about them, as reference to later pages in this issue will verify.

Speculation is rife, naturally enough, as to who will operate the first craft commercially, the identity of the craft, and the route chosen. It is highly likely that a number of experimental services will open up within a few months of one another. Our best wishes to those operators who take the plunge at this stage and our sincere congratulations to those responsible for developing the craft that make such services possible.

SETTING THE PACE

Eight years have passed since the introduction of the world's first scheduled hydrofoil service on Lake Maggiore. Since then the technical development of the hydrofoil has continued apace, but when compared with the jet airliner—a comparable transport innovation introduced at approximately the same period—none will deny that the rate of application of the commercial hydrofoil has been disappointingly slow.

In the face of such a hesitant attitude among possible operators, the bold action of U.S. Maritime Administration in planning and largely subsidising the H.S. Denison should be applauded. It sets an example that might profitably be emulated by maritime administrations elsewhere in the world. No doubt the Administration in general, and particularly the former colleagues of the late Colonel Charles R. Denison, who initiated the commercial hydrofoil studies for the Administration, are gratified by the tremendous response to their project. Twenty-eight firms have so far applied for consideration as operators of the craft, described later in this issue, and a further two companies have been so inspired by the Denison programme as to begin planning the construction and operation of hydrofoils of their own.

Certainly a growing interest in hydrofoils among the world's shipping operators is now apparent, and we believe that their present number will have been multiplied one hundredfold within a few years. For the record, today there are hydrofoil operators in Italy, Norway, Sweden, Venezuela, Greece, Finland, Yugoslavia, Egypt, North America and Japan. There are about a score, all told. During 1961, the 28 vessels they have in service will accumulate about 400,000 nautical miles and transport more than one million passengers in regular daily commercial operation in four continents.

We have not taken into account the craft in service in the Soviet Union, since at the moment we have no confirmation of the numbers involved.

People and Projects

None have fought harder for the recognition of the ground effect machine than **Christopher Cockerell,** probably the best-known pioneer in the field, and the man responsible for developing the highly successful Hovercraft principle. We are delighted that he was able to find time to send us a message for this issue.

Though generally widely quoted for his views on the state of this new art, the press apparently overlooked some interesting observations made by him when he was awarded the Viva Shield by the Worshipful Company of Carmen in the City of London. Here are a few excerpts:

"Mr. R. A. Shaw, Deputy Director of Aircraft Research, has stated publicly that in his opinion the Hovercraft industry will eventually be as big as the aircraft industry or the shipbuilding industry. Here is a vast export potential waiting to be exploited, far larger than that for supersonic airliners or rockets, or replacement luxury liners. At this moment there are perhaps eighty technicians and engineers working on Hovercraft in this country. There ought to be eight hundred.

"With our limited resources, it is only possible for us to tackle a few of the many likely lines of development. One glaring omission is the Hovercraft which will be designed to travel on tracks, like a train. The potential here is—London to Glasgow in two hours; or, if there is a Channel bridge, London to Paris in one hour—and these journeys will be from city centre to city centre, and at railway fares.

"We have had no approaches from the railways. The shipping industry is also slow to show an interest in ship-like Hovercraft. It must be realised that few high executives have the time or energy, or specialised technical qualifications, to sit back and take a long look at a concept as new as the Hovercraft. N.R.D.C. is doing great work, but for a project as large as the Hovercraft there still seem to be a number of awkward stages requiring a lot of money between the demonstration of an experimental craft and the production of viable, safe and exportable machines, not easily bridged by existing Government machinery.

"If the Hovercraft concept is to be fully exploited, then I estimate that we ought to be spending an average of 10 million a year on development for the next twenty years."

Since he gave this address, however, there is news that British Railways have become interested in his advanced new scheme, which may well make railways in Britain pay for the very first time.

* * * *

A newcomer to the field of hydrofoils is **de Havilland Aircraft of Canada.** It was announced in Montreal on September 10th that a contract has been awarded the company for the development and study of an anti-submarine hydrofoil craft by the Defence Production Department. The estimated cost in this fiscal year is $270,000. D.H. Canada is the third major aircraft company on the North American continent to start developing hydrofoils, the others being Grumman and Boeing. Grumman started work on hydrofoils in 1958 and Boeing in 1960.

* * * *

Carl Weiland, the Swiss inventor, and another pioneer in the development of ground effect machines, is now in America, working for the Reynolds Metal Company. William G. Reynolds, executive vice-president for research, met Weiland in Zurich and invited him to the United States to work on craft for Reynolds Metals. He has now built three GEMs, one quite small, a large one (now in the possession of the United States Marine Corps at Quantico, Va), and one now undergoing tests.

For this recent description of the third craft we are indebted to the *Courier-Journal,* of Louisville, Kentucky:

"A combined howl and roar echoes from the wooded Indiana slopes as the air boat picks up speed. The howl comes from a big fan, driven by a 160 h.p. Lycoming aircraft engine, which forces air out of a band of inch-wide jets around the underside of the flat-bottomed craft. The roar is produced by another engine, mounted high on the tail structure, which drives a reversible-pitch two-bladed airplane propeller. A rudder in the air behind the propeller is the only means of steering the low, bulky-looking vessel.

"Charles Johnson, a Reynolds pilot and former Curtis-Wright test pilot, 'flies' the boat. He's put in nearly 100 hours in it. On good runs, when all is going well, the boat hauls itself out of the water a good six or eight inches. It is then free of the drag of the water and can hit 75 m.p.h. or better.

"The Reynolds boat weighs 4,000 pounds and can carry about four people. The boat is a combination of boat and airplane. It was built by Aluminium Cruisers, and is built like a plane, with aluminium skin stretched over aluminium internal sections. The hull is filled with styrofoam.

"Engineers from General Electric Company, which makes jet engines at Evendale, Ohio, are conferring with Weiland and Reynolds engineers about power plants for future models."

We shall be receiving some technical information from the Company shortly. The craft is now in the last phases of its preliminary trials.

* * * *

Off shortly on the first of a series of visits to the Commonwealth countries is **Mr. S. P. Woodley,** of Vickers-Armstrongs (South Marston). He will introduce the Vickers range of Hovercraft first to Nigeria, then to Canada and, next year, to Australia. Among the applications for Hovercraft envisaged by Mr. Woodley in Nigeria is that of carrying goods from shore to ship over mudflats which could not be crossed by any other form of transport. In Australia one possible use is that of carrying cattle, saving loss of weight on long treks—a new and more economical approach to the novel "Air Beef" scheme.

Mr. Woodley will be helped on his sales tours by an air-transportable demonstration Hovercraft described later in this issue.

* * * *

A conceptual design of a nuclear-powered 306-ton ground effects machine which can hover over land, sea or ice, or cruise over the surface on a cushion of air has been prepared by **General Dynamics Corporation.** The machine could be used as a mobile power unit for remote areas, as an ocean-going missile-launching platform or as an anti-submarine vehicle.

It would travel at heights of 3 to 5½ feet above the ground or water, at speeds up to about 115 miles an hour. It could operate for more than a year without refuelling. The GEM would be a six-sided vehicle shaped like a clipped delta, with the nuclear reactor located at the centre of the delta, and the crew located in the apex of the clipped triangle.

The vehicle would be lifted and propelled by sustained thrusts of air from jets located around the edge, and directional control would be provided by varying the amount of thrust from the directional ducts in the rear. The GEM would be about 170 feet long and 125 feet at the widest point.

Initial studies involved the smallest sized GEM for which nuclear power would be feasible. Larger nuclear-powered GEMs could be cargo vehicles capable of carrying several thousand tons.

As a mobile power plant, the 306-ton vehicle could travel to bases in remote areas such as the Antarctic and supply immediate and long-lasting electrical power. It would also be useful as a hunter-killer anti-submarine craft, exploiting its speed and

EXPRESS—a PT 50 recently put into operation by Niarchos (Hellas) Maritime Co. Ltd., running between Piraeus, Spetsae and Hydra. On its initial trip King Paul of the Hellenes took the helm.

People and Projects . . .

its ability to go rapidly from hovering or floating to high speed.

The GEM would utilise a helium gas-cooled reactor with closed-cycle gas turbine power machinery, a combination offering high thermal efficiency and low specific weight. The use of nuclear power made possible virtually infinite endurance, as well as the capability of carrying heavy cargoes cheaply in large vehicles over long distances.

For low forward speeds, thrust would be obtained by deflecting the jets at the sides of the GEM with a series of variable-angle vanes. At high speeds, a mixed propulsion system would be used. Part of the thrust would be provided by deflecting the annular jets, part from a separate propulsion system.

The GEM also could float on the water. Because it would sit on the surface like a wafer, it would be almost immune to torpedo attack. In extremely heavy seas it could hover out of danger indefinitely.

* * * *

Bell's Air Scooter has aroused considerable commercial interest. The Allen Herschell Company Inc., of Buffalo, New York, has now been licensed to build and sell the craft for overland purposes. In addition to the commercial possibilities, it is believed that an Air Scooter with 30–40 h.p. might find military application as an all-surface courier vehicle.

* * * *

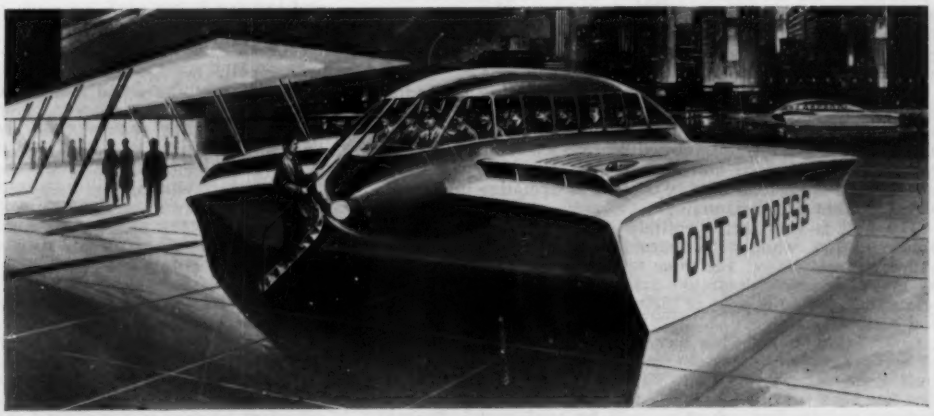
A lot of people liken publishing to the preparation of the traditional British cucumber sandwich. Thick wedges of advertising with a sliver of editorial between to remind you what it is all about.

Editorially this issue is thick, and for this we should like to express our gratitude to, among others, the many public relations people who have helped us—the invisible contributors who have greatly eased our task of preparing this first number. We should, in particular, like to thank Cdr. Deibler of the United States Navy, who must have devoted many hours to finding suitable references and contacting people on our behalf. Other people to whom we should like to express our appreciation are Frank O'Shanohun and Gavin Cochrane of Hovercraft Developments, Robert Mansfield and William C. Clarke of Boeing, Ann Baker of Baker Hydrofoil Company, Trevor Lyne of Bristol Siddeley Engines, F. R. Drew of Westland Aircraft Ltd., Thomas L. Tobin of Bell Aerosystems, J. Morton Newell of AiResearch Manufacturing, Arizona, Jack Tennant of U.S. Department of Commerce, Maritime Administration, and the News Bureau, Bell Helicopter Corporation, Don Flamm of Aeronutronic (Ford Motor Co.), and Carl Byoir and Associates, c/o Hughes Tool Company, Aircraft Division, and Walter S. Silverman of Reynolds Metal Company.

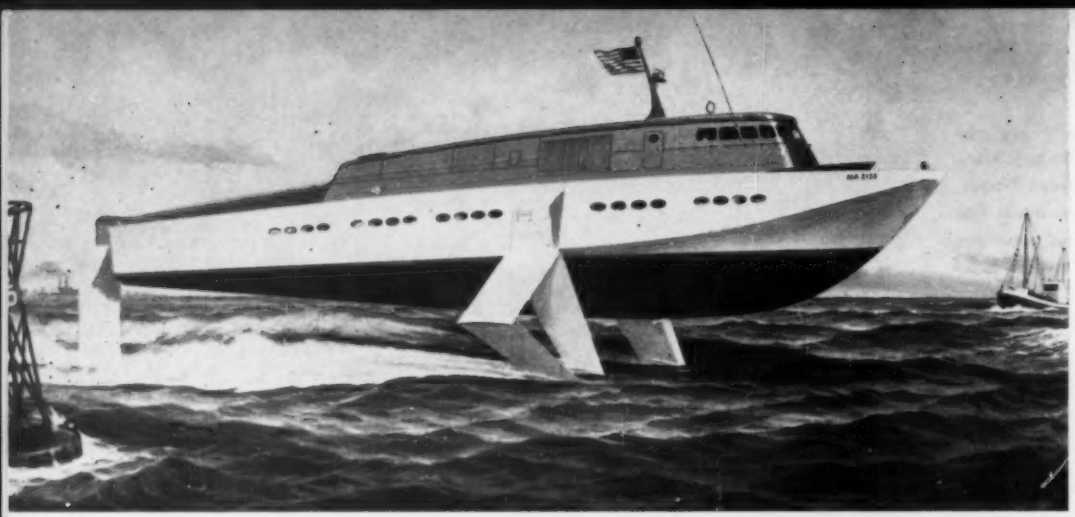
Japan is to develop a series of ground effect machines. In announcing this from Tokio recently, the Technological Research Institute of the Japanese Transport Ministry said that it had operated successfully a disc-shaped model of a hovercraft, a little more than three feet in diameter.

* * * *

From **Mr. C. F. Morris** of Denny Brothers we learn that the company is now planning a new, 75-ft. long hovership for 69-80 people, the actual number of seats depending upon the stage distance involved. The craft will have a 16ft. beam, lift about 6 tons and be capable of 25 knots. It has not yet been decided whether the craft will have a diesel or petrol engine.



A SHORT-HOP passenger ferry—one of several interesting design projects conceived by Bell Aerosystems.



Built for the U.S. Department of Commerce's Maritime Administration in a development and research programme aimed at improving marine transport systems, the H.S. (Hydrofoil Ship) DENISON is the

WORLD'S FIRST OCEAN-GOING HYDROFOIL

TO ASSURE that the water transport system of the United States is adequate to handle and encourage the nation's future growth, the Federal Government, through the Maritime Administration, supports the maritime industry in two ways. First, through direct subsidy funding or mortgage insurance programmes, and secondly by a concise research and development programme aimed at improving marine transport systems and equipment, and the development of new ship types or concepts. As part of this research and development programme, the Administration is now developing a new ship concept utilising hydrofoils for ocean commerce.

Maritime Administration engineers became interested in hydrofoil vessels in 1955 as the result of reviewing work being sponsored by the Office of Naval Research. The late Colonel Charles R. Denison, then Coordinator of Research for the Administration, sponsored the first Maritime Administration studies of commercial hydrofoils in 1958 with the Grumman Engineering Corporation. These studies led to the construction of the H.S. Denison.

An 80-ton craft, capable of carrying more than 80 passengers 850 miles at a speed of 60 knots, the Denison is intended to serve as a test vehicle and forerunner of considerably larger craft. Not only will the feasibility of the engineering concept be established, but actual operating experience will be gained in day-to-day commercial service.

The United States Government is paying about $1.5 million of the estimated $5 million cost of the craft, the remainder of the production costs being borne by the participating firms.

The Denison's primary power plant, used for foilborne operations, is a General Electric MS 240 gas turbine with a continuous rating of 14,000 horsepower. It is located above the main deck and within the aft end of the superstructure. Power is transmitted through the shafting and gear boxes of an "over the stern" drive to a super-cavitating propeller located at the lower end of the tail strut. Power for low-speed operation, with hydrofoils retracted, is provided by a 1,000 horsepower General Electric T 58 gas turbine. This drives two steerable water jet pumps which discharge below the hull, providing thrust for manoeuvering and docking.

The Denison features a self-stabilising hydrofoil configuration, in which surface piercing foils are located forward on each side of the hull and carry a major portion of the weight, while a fully submerged tail foil, located beneath the stern, carries the balance. The designed hull clearance is 5ft. above the water surface, and the craft should be capable of operating in 5ft.–7ft. waves without undue slamming.

The hull is constructed entirely of corrosion-resistant aluminium alloys, while welded steel has been employed for the hydrofoils and struts. The three struts are attached to the hull by hinged joints. A hydraulic actuating system is installed to rotate the hydrofoils clear of the water for hullborne operation and berthing.

Considerable thought has been put into this interim craft, and to make the transition from conventional craft to "winged" craft as painless as possible to potential operators, much attention has been paid to docking. In service it is anticipated that harbour and channel operations will be conducted hullborne, with the hydrofoils retracted, up to the maximum displacement speed of 7 knots. Once clear of traffic and shoal water, the foils will be lowered, the main engine started, and the craft can proceed foilborne at 60 knots to the vicinity of its destination, where the procedure is reverse. A crew of four—Captain, First Officer, Navigator and Engineer—will be sufficient to operate the boat, supplemented by stewards as required to provide service to the passengers.

It has been found that driftwood and other floating debris has little effect on foilborne boats. However, as protection against grounding or striking a submerged rock while foilborne, the foil struts have been designed to shear off at their hinges before any hull damage occurs.

Being of modest draft it can be brought alongside almost any dock without any unusual handling. The retracted main foils extend above the dock, overhanging it by about nine feet. Normal servicing and maintenance, as well as passenger handling, can be accomplished at pierside. The hydrofoils, which have to be kept clean of marine growth, can be serviced while in their raised position.

The gas turbine engines can be removed and replaced with the craft in the water. It is anticipated that Grumman-Dynamic Developments will train operating crews and provide maintenance and overhaul service.

Radio and Navaids

Navigation and radio equipment installed in the vessel includes VHF and HF transceivers, radar, loran, automatic direction finder, depth finder, and a gyro-stabilised magnetic compass. In addition there are systems for speed indication, automatic monitoring, fire detection and extinguishing and intercommunication. The craft can be steered both manually and automatically from the gyro-compass. It is also stabilised in pitch and heave motions. Adequate heating, air conditioning and lighting is provided.

Performance

Originally the Denison was designed with supercavitating foils and was to have had a speed capability of 100 knots. For a number of reasons the supercavitating foils were replaced with subcavitating foils and the design speed lowered to 60 knots. Primarily as a result of Navy interest, a joint Maritime-Navy research effort is being pursued to design and construct a set of supercavitating foils for installation on the vessel in approximately two years. These foils should permit speeds up to 100 knots. The existing gas turbine, transmission and hull are designed to accommodate such speeds.

Current cruising speed of the craft is 60 knots, and the "take-off" speed, or speed to lift the craft out of the water, when fully loaded is 30 knots. While foil-borne, the craft's turning radius is approximately 1,000 ft.

The 37 tons of weight which the craft is capable of carrying must be distributed between cargo, in the form of individuals or goods, and the necessary fuel and operating personnel. If the range is short, less fuel will be required for the trip, with an attendant increase in commercial cargo-carrying capacity. It is

estimated that a trip of 850 miles would permit the carriage of 10 tons of paid cargo or the equivalent in passengers.

While not designed for commercial use, the Denison can be outfitted to carry 70 to 80 passengers in comfort. Because the main engine has been located on the deck, where it is readily accessible for servicing or removal, virtually the entire area below deck is available for passengers or cargo space. A vessel of comparable size, designed specifically for passenger service, could accommodate approximately 200 passengers in comfort in aircraft-type seating.

Commercial Operation

Request for approval of the craft for commercial operation has been made to both the Coast Guard and the American Bureau of Shipping, and both bodies are reviewing the design and construction. Because of the experimental nature of the craft, however, actual test results will be required before it can be classified or certified for commercial operation.

Test and technical evaluation of the H.S. Denison should be completed in early 1962, at which time plans call for placing the craft in commercial service.

Twenty-eight firms have already applied for consideration as operators. The applications have come from all areas of the United States, including the Atlantic, Pacific and Gulf Coasts, the Great Lakes and Hawaii. Applicants proposed a wide variety of projected services, ranging from commuter services in metropolitan areas, service from the United States mainland to Bermuda, and also to Nassau, an inter-island service for the State of Hawaii, other contiguous and non-contiguous domestic services, and U.S.-Foreign in the Caribbean and Gulf of Mexico. Other areas of suggested commercial operation included deep sea fishing, off-shore drilling operations, and use on the Atlantic Missile Range.

In addition to interest of private companies in commercially operating the Denison, two companies have been inspired by the Maritime Administration's research and development into hydrofoil craft and their possible use to begin planning the construction and operation of their own ships.

A contract has been signed between Grumman Aircraft Engineering Corp. and the Everglades-West Indies Steamship Company of Fort Lauderdale, Florida, for construction of two hydrofoil passenger ships. It is planned to use the ships in high-speed service between Fort Lauderdale and Nassau in the Bahama Islands, initiation of the service being anticipated prior to the 1962-63 tourist season.

The contemplated ships will be 65 feet in length, powered by gas turbine engines, and will carry 70 to 100 passengers at speeds ranging up to 60 miles an hour. Interior arrangements and passenger accommodation will be similar to those aboard modern jet aircraft, providing a high degree of passenger comfort. It is anticipated that the saving in terminal ground travel over aircraft passage will offset the faster speeds of the aircraft.

This contract is contingent upon the successful testing of the Denison upon its completion, making it a direct outgrowth of the research programme conducted by the Maritime Administration to stimulate the development and use of hydrofoil craft in the United States.

In similar fashion, it is anticipated that Maritime Administration-sponsored studies into the feasibility of constructing hydrofoil craft of greater size—up to some 500 tons—possibly higher speeds, and perhaps greater cruising range may point the way to a major mode of transportation for the future.

Basis for Research

Many interesting facts about the Maritime Administration's Hydrofoil Programme were revealed in a paper delivered to the Hydrofoil Transportation Conference, sponsored by the University of California, earlier this year. The authors, Richard P. Goodwin and James A. Higgins, gave a résumé of research undertaken for the Administration and indicated the great importance attached to the programme.

Grumman's investigation began with a parametric study of hydrofoil vessels and the report, "Study of Hydrofoil Seacraft," has been published by the Office of Technical Services, Department of Commerce, in Washington. The purpose of this study was to determine the type of hydrofoil craft best suited to a future express cargo and passenger application and to establish design criteria for such craft. The study investigated speeds ranging from 50 to 200 knots, displacement from 100 to 3,000 tons, and ranges from 400 to 3,600 nautical miles. The study was not limited by hardware or economic considerations.

Design Study

Encouraged by the results of the parametric study, the Administration contracted with Grumman in 1959 for two design studies for experimental vessels, one conventionally powered, the other nuclear powered. Each of these designs utilised supercavitating foil systems and was designed to operate at speeds near 100 knots. These studies were carried out in complete detail, including contract plans to define all the problems involved in constructing such craft.

The vessel developed by this study was an 80-ton, 80–100-knot test vessel powered by an aircraft gas turbine, with provision for installing a lightweight aircraft nuclear power plant when such plants are available. The craft envisioned the use of supercavitating hydrofoils and propellers.

The test vessel described in the 1959 study was a highly experimental project, especially the hydrofoils and the high speed. In January 1960 a contract was placed with Dynamic Developments, Incorporated, a subsidiary of the Grumman Aircraft Engineering Corporation, to construct the modified version experimental test vessel, utilising a gas turbine power plant and subcavitating hydrofoils, with speed capabilities to 60 knots.

Within the next five or so months the Administration expects to have accumulated sufficient data to permit the design of a commercial vessel larger than the Denison. They hope the data will be sufficiently compelling to persuade industry to design and build hydrofoils on a large scale and also to encourage a very large number of operators to use them.

PERFORMANCE SUMMARY

Max. speed, foilborne	60 kt.
Max. speed, hullborne	7 kt.
*Take-off speed at 80-ton displ.	30 kt.
Range with 10-ton payload at 60 kt.	855 n. mi.
Range with zero payload at 60 kt.	1,065 n. mi.
Turning radius, foilborne	1,000 ft.
Cruise power at 60 kt., 80 tons	6,500 h.p.
Max. continuous power, 80 deg. F day	14,000 h.p.
Max. power, 80 deg. F day	16,500 h.p.

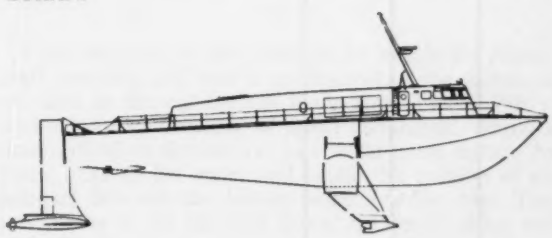
** Minimum operating speed when foilborne.*

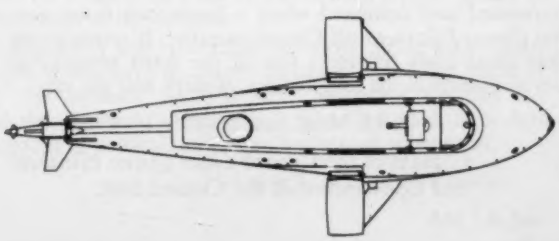
PRINCIPAL DIMENSIONS

	Foils Raised	Foils Lowered
Length overall	128ft. 9in.	117ft. 7in.
Beam	41ft. 0in.	45ft. 0in.
Draft	6ft. 3in.	15ft. 5in.
Hull length	104ft. 8in.	
Hull beam	23ft. 0in.	

NAVIGATION EQUIPMENT

VHF transmitter/receiver.
HF transmitter/receiver.
Radar.
LORAN.
Automatic direction finder.
Depth finder.
Gyro stabilised magnetic compass.





MESSAGES . . .

When "Hovering Craft" first began to crystallise as a separate, different, identifiable type of vehicle, there was no name for them, and if one wanted to talk about them one had to give a brief description of the whole thing and then go on to a discussion of some particular aspect.

My wife and I tried to find a name and settled for the not altogether appropriate word "Hovercraft." Soon after this the press, also at a loss for a name for them, adopted it, and although the press is not responsible for the models and the SR.N1 and the research work, it is certainly due to their efforts, and to the radio, that so many people have heard about this new vehicle.

However, it is still not much good advertising for a "Hovercraft Engineer," and it is at this point that the technical press can be of the greatest assistance in making more widely known the basic technical details and the technical advances in this new subject, for there can be little progress in a vacuum. Later on, and equally important, the technician, through the technical press, will hope to learn something of the operator's difficulties and requirements.

We, all of us who have forsaken the comparative safety of existing occupations and have thrown in our lot with this new venture, wish HOVERING CRAFT AND HYDROFOIL well, and may it prosper.

C. S. COCKERELL,

Hovercraft Development Ltd.

As Captain of the world's largest liner, and as one who has spent 44 years of his life as a seafarer, I am watching with great interest the evolution of hydrofoils and hovercraft. In fact, I and 2,000 passengers were impressed and delighted when a hovercraft came near the *Queen Elizabeth* off Cowes recently. It seems to me that these craft represent one of the most remarkable developments in the long history of ships and the sea.

D. M. MACLEAN, D.S.C., R.D., R.N.R.,

Captain of the Cunard Liner *Queen Elizabeth* and Commodore of the Cunard fleet.

The appearance of a periodical, HOVERING CRAFT AND HYDROFOIL, will certainly be welcomed by all technically interested circles, especially in the marine field and in particular, of course, by those of us who devote most of their time to the further development of these modern means of transportation.

Since there exists no other economically feasible way of increasing the speed of watercraft, which has been lagging behind aircraft and land vehicles in this respect for a long time, it may be safely assumed that both, the hovercraft as well as the hydrofoil boat, have come to stay. Undoubtedly both are still in their infancy or their 'teens, and are likely to undergo many changes and alterations in the course of their further perfection.

By spreading information and knowledge about these new craft and by inviting competent engineers and businessmen to discuss technical and economic problems connected with their design, manufacture and application in the pages of your new publication, you will be able to contribute greatly to their further development.

On the birthday of HOVERING CRAFT AND HYDROFOIL I want to congratulate you and to express my best wishes for success and for many happy returns of the day.

BARON V. SCHERTEL,

"Supramar" A.G.

I am intrigued by the principle on which the Hovercraft operates, and find it reminiscent of the technique we used in the old biplane flying-boats of the 1920's, which were so deficient in speed and range. Many a time, arrival at destination was made more certain by flying close to the water and riding the cushion of air jammed between the bottom wing and the sea. This enabled us to put the nose down, reduce the drag, and add a few knots to our airspeed.

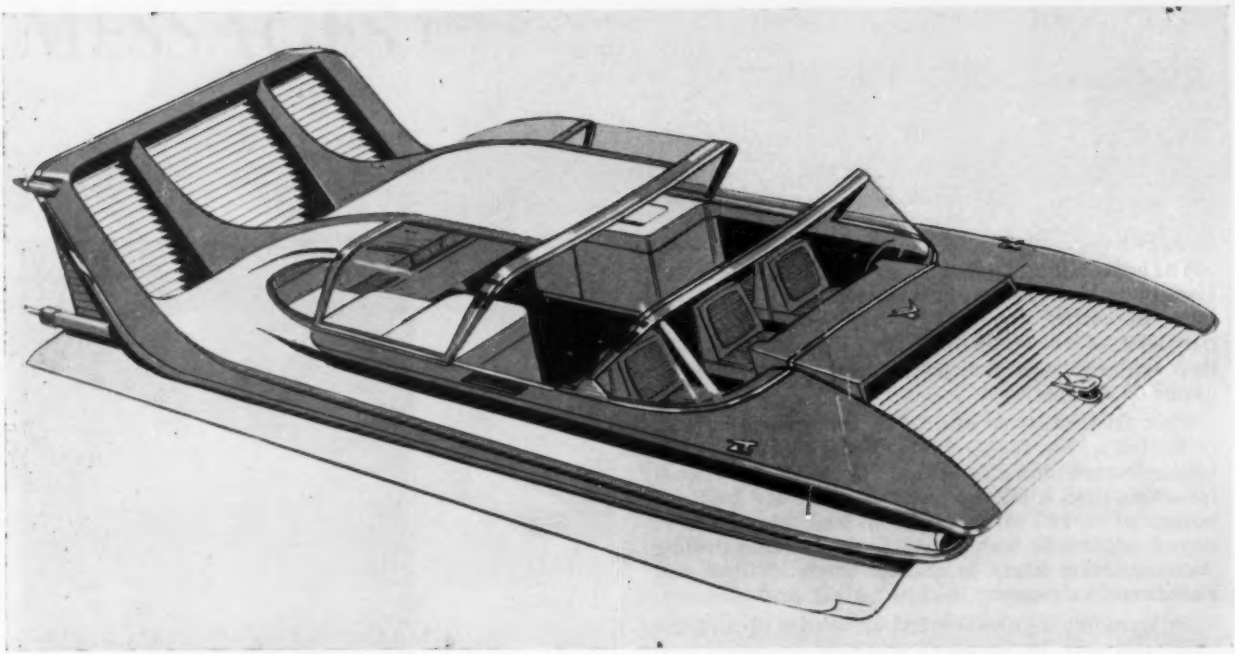
If the Hovercraft can be immune from the effect of rough seas and can have a cruising speed sufficiently high to ignore the effect of head wind, then there must surely be a great future for it on cross-channel routes—always providing cost of operation compares favourably with that of the displacement vessel (I nearly said "surface transport").

Presumably existing seaport facilities could be used by Hovercraft and, if the vehicle can be developed to take the necessary hurdles, airport facilities as well. Thus, it will be possible to avail of the terminals most suited to the needs of the traveller.

Finally, if the Hovercraft develops along satisfactory lines, it will have to change its name. All I can think of at the moment is "Flivver," nickname for the old Model T Ford. After all, it also indulged in a fair amount of vertical, as well as horizontal, movement.

CAPTAIN J. K. KELLY ROGERS,

Aer Lingus.



Built by National Research Associates, one of the pioneers in the field of ground effect machines, the first commercially available air-cushion water-craft is the

CUSTOM-STYLED AquaGEM

AIR SPORT is the name given to this AquaGEM variant, intended as a high-peed luxury yacht. It reaches 50 m.p.h. and has sleeping accommodation for four.

NATIONAL RESEARCH ASSOCIATES have built more man-carrying ground effect machines—more than twenty of various designs and sizes—than any other company. Though founded only in 1958, it has managed within the short space of three years to build an imposing collection of cushion craft which includes the first man-carrying machine for the U.S. Government, and the first gas turbine powered machine—ordered for the U.S. Marine Corps.

Design studies have ranged from a flying tank and even bigger craft of up to 50 tons for the U.S. Armed Services, to an eight-foot diameter Flying Saucer licensed for use in Disneyland.

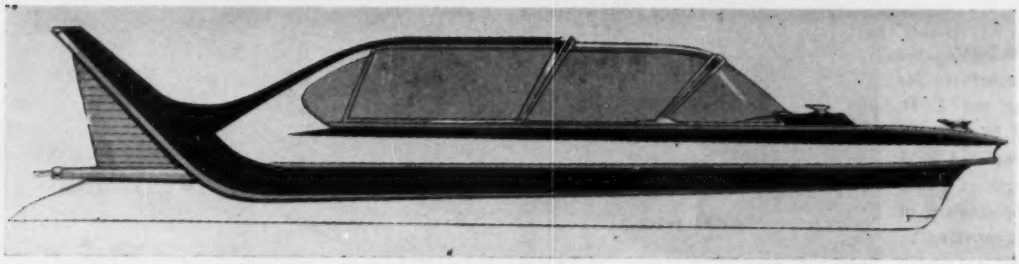
Now, after months of patient experimentation, the company has taken the air-cushion vehicle to the stage where it has, in a practical and commercial sense, come of age. Production has now started on a strikingly attractive and useful trio of triphibians called AquaGEMs. Priced at about $16,000 each, these are the first commercially available air-cushion water craft.

The three models are the Air Carrier, for general utility transport; the Air Liner, a high-speed water-taxi for 19 people, and the Air Sport, designed for hunting, shooting and fishing week-ends, and complete with bunks and galleys. For a total of 240 h.p., these craft, which are 30ft. long by 9½ft. wide, are capable of attaining 50 m.p.h. A displacement craft of the same size would require from five to ten times this horsepower to attain the same speed and it would not be possible to operate it in very shallow water.

The AquaGEM's levitation capability gives it a broad scope of operation—deep or shallow water, over sand bars and other relatively flat ground areas, including marsh grasses, mud and so on. It can operate as a displacement vessel as well at low speeds up to 15 m.p.h., and eliminates time-consuming docking

FLYING WORK HORSE of the fleet is the Air Carrier. One intended application is for carrying perishables and general cargoes between vessels at sea and coastal towns at high speed. Payload is three-quarters of a ton.

CUSTOM-STYLED AquaGEM . . .



SEATING NINE PASSENGERS and an operator, the Air Liner is intended for commuter services, as a water taxi, or for sightseeing. It will skim over channels, sand bars, bogs and marsh areas.

problems by simply pulling onto beaches or a landing pad.

Thrust to drive the AquaGEM above or through the water is supplied by an 80 h.p. two-cycle, water-cooled engine which drives two large fans. A system of aerodynamic surfaces in the propulsion air stream is used for directional control and attitude correction.

A forward-mounted 40 h.p. two-cycle, water-cooled engine driving two small fans provides a cushion of air to support the craft and payloads up to 1,500 lb. The standard 40-gallon fuel tank fitted is sufficient for a cruising range of 150 miles, with an operating cost of 8 cents a mile.

The maximum surface clearance is 1 inch beneath the skeg, and beneath the chamber, 5 inches.

Construction

In the construction of these craft extensive use is made of anodised aluminium, which is utilised for the frames and bulkhead, fan shrouds and frames, fan inlet louvres and trim, and the skeg rubrails. The skegs themselves are of plastic, also the cab roof and decks. The skeg cutwater is in stainless steel. The side windows are in clear plastic and the windshield in glass.

Instruments

Instruments fitted as standard to the three models are: lock ignition starter switches, engines temperature gauges, ammeter, tachometers, fuel gauge, chamber pressure gauges. Optional extras include an air speed indicator, water speed indicator and an engine hour indicator. Steering is by combination air and water rudders, operated from the wheel by cable, and the throttles are of dual lever aircraft type. The electrical system is 12 volt.

Standard Equipment

Fittings include chromed international navigation lights, step pads and handrails, anchor chock and rope cleats, and a stern light with its pole and ensign. Built-in twin headlights provide full illumination for high-speed travel at night. Aircraft styling has been used for the control dash panel and steering wheel, since it was felt that this would assist in quick monitoring and control of these craft at high speeds. Also provided are dual electric windshield wipers, an electric horn, a complete 12-volt electrical system, battery, a flight styled operator's chair with back and seat cushions, and a five-pound CO_2 fire extinguisher.

APPLICATIONS

Air Carrier

Workhorse, offering high-speed cargo and general utility transportation with zero draft capability. Equipped with a cutaway hardtop roof for operator weather protection. Cargo area 8ft. wide by 12ft. long. Two forward-mounted extra crew seats.

Air Liner

Designed for commuters, sightseers, intercoastal and river travel, this totally enclosed model is fitted with nine passenger seats and one operator seats. Styled with decorative sound-proofing materials.

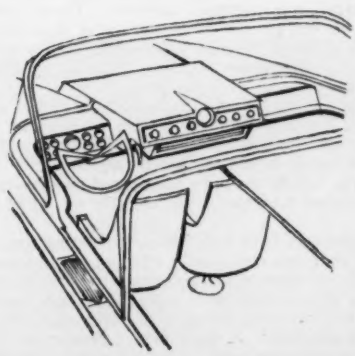
Air Sport

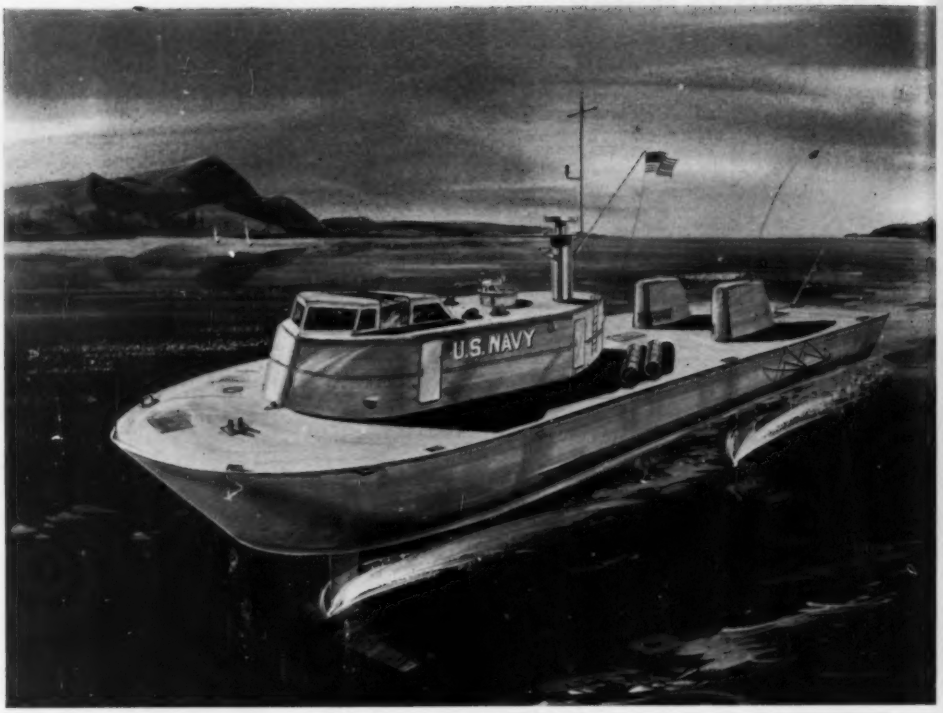
Luxury craft. Completely enclosed hardtop with a full-width sliding cockpit hatch, two convertible chair bunks and a rear seat bunk, two slideaway tables, toilet, storage cabinet and stove unit, 10-gallon water tank and a sink unit.

Specifications

Overall length, 30ft.
Beam, 9ft. 6in.
Maximum freeboard, 47ft.
Cockpit length, 16ft.
Cockpit width, 8ft.
Cockpit depth, 2ft. 7in.
Cab headroom, 4ft. 8in.
Draft (no air), 15in.
Design payload, 1,500 lb.
Weight empty, 1,700 lb.

THE STANDARD aircraft-type styling used for the control dash panel and steering wheel.





BOEING IS BUILDING the PC(H) hydrofoil subchaser for the U.S. Navy at the J. M. Martinac shipyard in Tacoma. Expected to be completed in 2½ years, it has a length of 115ft., and a full load displacement of 110 tons. Power is provided by two 3,000 h.p. gas turbines during foilborne operation. Value of the contract is more than $2 million.

BOEING'S NEW FLYING BOATS

EVER SINCE C. A. de Lambert, the French-born Russian national, demonstrated his steam-driven hydrofoil on the River Seine in 1891, hydrofoil design and construction has been primarily the work of marine architects and designers. With only a few exceptions, the aircraft industry ignored the field. It was not until after the second World War that the skills which created some of the world's great aircraft were turned to this new field of transportation.

Boeing's interest in hydrofoils did not become generally recognised until 1960, when the U.S. Navy announced that the company had been awarded a $2 million contract for construction of a hydrofoil subchaser, the 110-ton PC(H). The company's interest was natural, however. There are numerous similarities in design and construction of hydrofoils and aircraft. Both systems require lightweight structures and light, high-efficiency propulsion systems. Similar problems are encountered in foil and wing designs.

The subchaser, the biggest hydrofoil yet built, was designed by the U.S. Navy, but many of the subsystems, such as the automatic pilot, the power transmission system and other components, are being developed by Boeing.

The PC(H) will fly on fully submerged, subcavitating foils, a system developed and tested successfully on other craft by the Navy.

These submerged foils lack inherent righting forces. Running submerged, they are not greatly affected by surface waves and troughs and can operate at a relatively constant level in low sea states. This system requires a separate system for stability. In the PC(H) it is provided by an automatic pilot similar to those employed in airplanes. A significant difference in the hydrofoil system is the electronic device which senses height above the water, permitting accurate height control. In the PC(H) the autopilot output hydraulically operates trailing edge control surfaces. The system will allow the ship to maintain high speed in rough seas, a necessity for military craft. It was this necessity which dictated the submerged foil system for the PC(H).

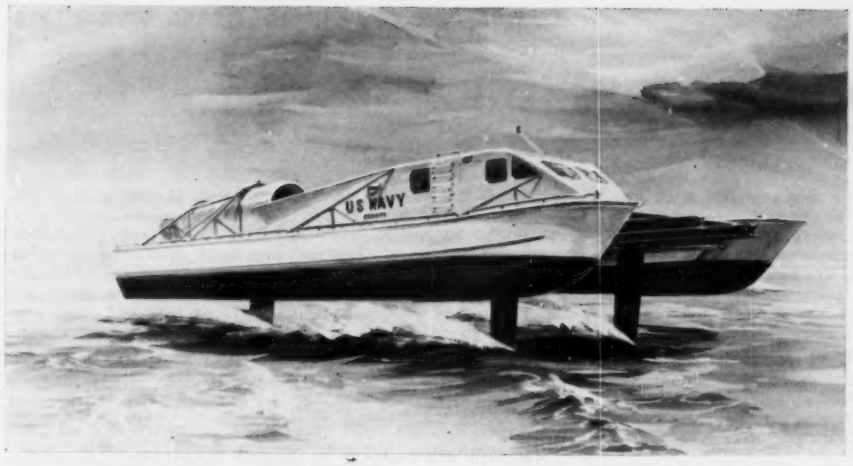
When hull borne, the 115-foot ship will be powered by a 600 horsepower diesel engine. The power will be transmitted through a right-angle drive to a propeller which can be retracted at take-off to reduce drag. When foil borne, the ship will be propelled by two gas turbines, each capable of generating 3,100 h.p. Transmission of the power of the turbines is also by right-angle drive, into nacelle-enclosed propellers, set at the intersection of the aft foils and struts.

Top speed of the craft is expected to be between 40 and 50 knots. Delivery is scheduled for late summer, 1962.

Anti-submarine warfare is one of the most obvious uses for hydrofoils. They promise to regain the speed advantage lost by the surface ship in the last few years to the nuclear submarine. The PC(H), for example, is designed to employ the "grasshopper" technique in anti-submarine warfare. The craft will race foil-borne to a search area, stop and listen with sonar gear, and then race on to another area. Propelled at high speed, it will be able to patrol a large area in a short time.

There are other military possibilities for hydrofoil application:

At present, amphibious craft are limited to approximately seven knots, because the hull form is dictated by beaching and land traversing requirements. The water-borne speed can be greatly improved by the addition of retractable hydrofoils. When they are extended, the craft can attain foil-borne speeds of 30 to 40 knots. When retracted just before beaching, the craft



"FRESH-1," A TWIN HULL hydrofoil test boat built for the U.S. Navy by Boeing. A turbofan jet engine will provide a foilborne speed of 100 knots. The craft will be capable of testing a variety of supercavitating foils.

BOEING'S NEW FLYING BOATS . . .

would resume operation as a conventional amphibian. Development efforts for this type craft have been under way for several years by both the Navy and the Army.

A quick-reaction transport is another possibility. The addition of hydrofoils to a ship capable of beach landing would make it possible to transport armoured and mechanised units expeditiously to almost any beach or harbour in the world, prepared or unprepared.

Systems analysis programmes are currently under way at Boeing, the Navy and other segments of private industry to determine system requirements for the application of hydrofoils to those and possibly other Naval missions.

The breakthrough from subcavitating to supercavitating foils should double the speed of hydrofoils and result in considerable enhancement of their military potential. In this connection Boeing was recently awarded a contract for the design and construction of a 15-ton experimental supercavitating hydrofoil craft, the Navy's "Fresh-1."

This new hydrofoil boat, in the view of Rear Admiral Ralph K. James, Chief of the U.S. Navy Bureau of Ships, is an essential and logical step in the Navy's accelerated research and development programme aimed at gathering the knowledge necessary to build large, high-speed, ocean-going hydrofoil ships.

The unconventionally shaped craft will have twin hulls, joined together in a catamaran arrangement. Power for hull-borne cruising will be supplied by two 75-horsepower outboard motors. A turbofan jet engine, generating about 18,000 pounds of thrust, will be utilised to push the craft to foil-borne speeds. Theoretical studies indicate top speed will be around 100 knots. The highly instrumented craft, operating as an extension to Navy test basin and theoretical studies, will provide detailed information on the performance of different supercavitating hydrofoil configurations under actual rough water conditions.

The company is continuing to develop its capabilities in the hydrofoil field through a vigorous programme of research in the technical areas related to the design of advanced hydrofoil vehicles. Included in this research are hull characteristics and configuration studies, subcavitating and supercavitating foil studies, and studies of supercavitating propellers and advanced propulsion systems.

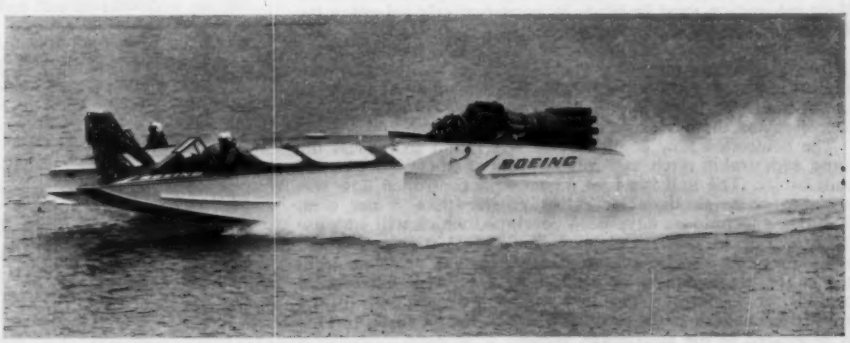
A programme of model testing is being conducted in conjunction with analytical studies. Individual tests have been conducted in facilities in widely separated locations, including the Norwegian Ship Model Experimental Tank at Trondheim, Norway, the Netherlands Ship Model Basin, Wageningen, Holland, and the University of Michigan, California Institute of Technology and the Stevens Institute in the United States.

At Boeing's own laboratories in Seattle testing is currently under way on structural materials and their fatigue characteristics. A cavitation erosion investigation is also being run. In addition, the Boeing computer facilities are being used for stability and control studies.

The company recently put into operation a high speed hydroplane which was conceived as a testing vehicle for all types of advanced marine shapes. The craft promises to be ideal for use in preliminary testing of hydrofoils and is expected to be used extensively in connection with the Fresh.

The craft has been dubbed the Aquajet, and is shaped like the claw of a lobster. Foils and hull models will be suspended on the test mount at the front of the craft between the sponsons. Propulsion, also by jet engine, is expected to push the 38-foot craft to a maximum speed of 100 knots. Gross weight is 11,600 pounds. It is currently undergoing test and calibration.

Test models suspended in the water will be monitored by electronic data-gathering equipment and by direct observation. All test runs will be on Lake Washington, near Seattle. Two courses are planned, one 1¾ miles long and one 2¾. A typical run will last one minute. The Aquajet will not be used for refined testing of foils, but as a tool which will be capable of developing fast, preliminary information and point in the proper direction for further basin testing.



BOEING AQUAJET is used to test new types of foils at speeds up to 100 knots on Lake Washington. Models under test are attached to fixture between the twin prows.

BELL'S NEW APPROACH

BELL'S RESEARCH WORK in the GEM field started in 1959 with the object of developing an understanding of the phenomena associated with GEM principles. Present research effort is directed towards the development of means for achieving high performance, good stability and effective control for both over-land and over-water operation.

Research to date has been divided between a theoretical and an experimental approach. Initial thoeretical work is verified by experiment; the experimental results are, in turn, used to develop the theory further. In addition to the primary effort, Bell are making the maximum use of the researches of other organisations by carefully reviewing their literature and by visiting those agencies where GEM research is in progress.

Bell began work in the GEM field by deriving equations for predicting hovering performance of the basic GEM types. Later, model tests were conducted and correlated with theory. The five-foot model used for these tests was powered by a 2 h.p. electric motor and was fully instrumented. Several different configurations of annular jets and plenum chambers were tested; as a result, hovering performance of these configurations can now be accurately predicted. Future test work along these lines will include the evalution of the hovering performance of new GEM configurations which appear to offer promise.

During the performance evaluation of the basic GEM types, it was found that the performance of the annular jet could be obtained with the much simpler plenum chamber. This was achieved when the internal air flow attached to the walls of the plenum chamber and discharged vertically around the periphery of the base. Several techniques for controlling the flow have been tested. One such technique is to use guide vanes below the fan to turn the air and make it flow parallel to the inside wall of the plenum. The desired internal flow can also be obtained by the coanda effect (that is, a high velocity jet of fluid ejected tangentially to a curved surface will follow that surface).

Performance of the controlled flow configuration is compared with the annular jet and plenum chamber on the accompanying graph.

The aerodynamics of the GEM in forward flight are quite complex and have not yet been fully defined. Empirical methods can be used to predict the forward flight performance of the plenum chamber with satisfactory accuracy. As yet, it has not been possible to predict the forward flight performance of the controlled flow and annular jet configurations, because the air flow at the curtain of air across the front of these GEM configurations has not been adequately defined. Bell's whirling arm test facility is being used to develop an understanding of the flow phenomena. It is believed that it will soon be possible to describe the flow conditions and power requirements of the annular jet and controlled flow configurations in forward flight with simple analytical techniques. For the present, forward flight calculation must be made by conservatively assuming the flow conditions on the front curtain.

One of the primary advantages of the plenum chamber is that it possesses strong stability. The annular jet in its basic configuration has undesirable stability characteristics. As hovering height increases above the thickness of the jet curtain, stability decreases and the device becomes unstable in pitch and roll.

The controlled flow configuration was found to possess the same undesirable pitch and roll stability characteristics as the annular jet. The Bell five-foot model with controlled flow was unstable at height/diameter ratios greater than 3 per cent. Stabilising techniques have been developed which will stabilise the model up to a height/diameter ratio of 11 per cent. These techniques can also be adapted to the annular jet. One technique for stabilising a controlled flow GEM configuration consists of creating a chamber which will respond to the stabilising changes of the static pressure of the jet curtain. This is illustrated in the accompany sketch.

Another technique for stabilising the controlled flow configuration GEM is to divide the flow into two concentric discharges. Each side will then act as much as an independent GEM which has inherent vertical stability. This also is illustrated.

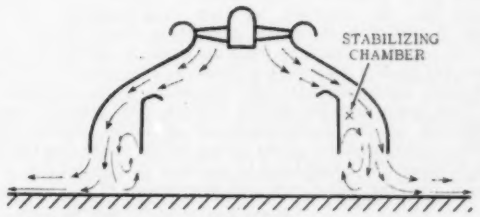
Research will continue to develop these techniques further and to explore new techniques.

The development of satisfactory control and propulsion systems for GEM vehicles is complicated because adverse moments can result when the primary air source is used for control. To enable satisfactory vehicle design, a concentrated research effort in this area is required. The success of a given GEM will rest heavily upon the capabilities of the control and propulsion systems.

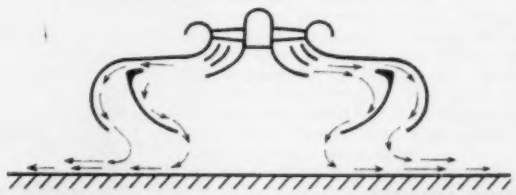
In this area, Bell has made significant strides; a one-third scale model of a man-carrying GEM has been used to test many forward propulsion and control schemes. The best propulsion system resulting from these tests uses a combination of vehicle tilt and a rearward facing air jet. An internal control baffle is used to produce the desired pitching moments. Although this scale model was a plenum chamber type of GEM, the longitudinal control system uses control flow techniques. A major portion of the company's future GEM research will be devoted to the development of effective control and propulsion systems.

The company feels that even in this early stage of the ground effect machine concept, it is important to proceed with the design and development of an operational vehicle. It is only by use that the ground effect machine will find its place among existing transportation media.

In the selection of what type of vehicle to develop, it was considered important to choose one which not only satisfies a variety of mission requirements, but is also appropriate within



Stabilizer Controlled Flow GEM



Controlled Flow Configuration Stabilized By Two Concentric Discharges

the existing state of the art. It was also believed that the vehicle should not be limited to only one type of operation but be sufficiently flexible to allow the development of operational techniques for over-water and overland. In essence, the device should be designed to be extremely flexible, so that through use, its place as a transportation medium will be found. Bell engineers feel that to achieve this flexibility and utility, the power loading of the GEM will be severe, to the order of 10 lbs./h.p. It is probable that power requirements for future specific applications of GEM principles need not be as severe.

Even with the high power requirement, the GEM offers considerable advantages. Simplicity, reduced maintenance, operation by non-skilled personnel, very large ratio of payload to empty weight, extreme overload capability, are some of the obvious advantages to be further exploited.

The type of vehicles and tentative missions will dictate the general configuration of the vehicle. The design must include space provisions for seating and for payload. It is important that in establishing the configuration, consideration be given to minimising air turning losses. For this reason, it was thought to be desirable to tilt the fans forward for a high forward speed propulsion efficiency. A large inlet fan area is desirable for improved hovering efficiency.

From the standpoint of overall hovering efficiency, it is desirable to make the vehicle as large as practical. This is because the hovering height is a function of the vehicle's base dimension as well as the base loading. Irrespectively of configuration or use, the size of the vehicle should not be so large as to limit the utility of the machine.

At the present state of the art, hover height will be limited to a fraction of the vehicle's width. This will penalise the smaller vehicles in some situations, but the smaller vehicle will be able to go around or in between obstacles which larger vehicles would have to pass over. The minimum hover height required will depend on the types of terrain over which the vehicle is to operate. For most over-land operations, it is believed that a hover height of one or two feet will be adequate. A flexible skirt will allow traversing objects higher than the hover height.

If the GEM is to be economical, it must operate at an appreciable cruise speed. A cruise speed of 50 m.p.h. should be adequate. The static performance of the propulsion system should allow the GEM to push through high brush and negotiate 30 to 45 per cent slopes. If the GEM is to operate primarily over water or on semi-prepared surfaces, a much lower static thrust capability would be adequate.

The control system of the GEM should be such that co-ordinated turns may be made at cruise speed. It should be possible to stop in a reasonable distance without resorting to landing the vehicle. These requirements can be met by proper use of controlled flow techniques.

After the type of vehicle has been chosen and a preliminary design completed, an inexpensive scale model should be constructed and tested to develop such items as the propulsion and control systems, and to investigate the stability of the machine. Bell's experience has shown that inexpensive models can be used assure the success of full-scale vehicles.

Relying heavily upon the model test results, the full-scale vehicle should be designed. Experimental aircraft techniques should be used to expedite the design and construction phases of the development.

Tie-down test and fan over-speed tests should be made to assure structural adequacy. Flight development work should be done with the full-scale vehicle to obtain the most effective control and propulsion systems and to make any modification which might increase the utility of the machine.

At this point the GEM would be ready for operational testing.

TYPICAL BELL VEHICLE DESIGNS

The Leap (The Land Effect Air Pickup)

The mission of the Leap is to provide a means of accomplishing long-range reconnaissance, counter-reconnaissance and screening operations for armoured and infantry cavalry units as well as smaller reconnaissance elements. Units equipped with these vehicles can operate as security forces on economy of force missions over wide fronts and extended distances. The Leap will assist in special operations such as river crossings and inland water operations.

It is a three-seat vehicle of small size and high power. The width is 8 feet and the length is 17 feet. A windshield is used in place of a full canopy to permit rapid entry and egress. The Leap has 200 h.p. and its empty weight is 1,000 pounds. The flat surfaces along each side are used to carry bulk cargo.

A flexible skirt increases its obstacle clearance capability. The structure is designed to permit the Leap to slide over ridges and other obstacles that are higher than its normal operating height.

Three soldiers and fuel for four hours can be carried at the design gross weight of 1,800 pounds. At this weight, the hover height is 1.5 foot and the slope capability is 38 per cent. Operation in brush and heavy vegetation is accomplished by bending or crushing the vegetation forward and then sliding over it. This is possible because of the high forward thrust capability. At the design weight and a cruise height of 6 inches, the maximum speed is 70 m.p.h.

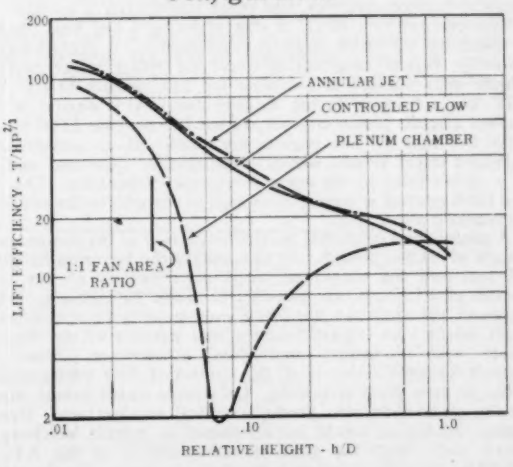
Command Car

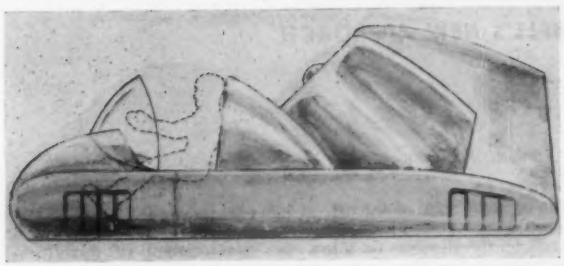
The mission of the Command Car is to provide combat units with an intermediate size vehicle which can operate at high speeds within the battle area. Some of the specific applications of this vehicle are as a mobile command post for unit commanders, a small combat weapons carrier for crew-served weapons, a medical evacuation ambulance, and as an administrative vehicle in rear areas.

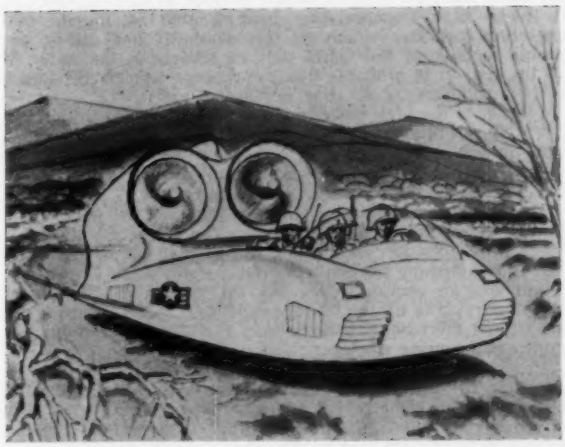
It is a six-seat vehicle powered by a 200 h.p. aircraft engine driving two 52-inch diameter fans. Its planform is 10 x 22 feet. The empty weight is 1,350 pounds.

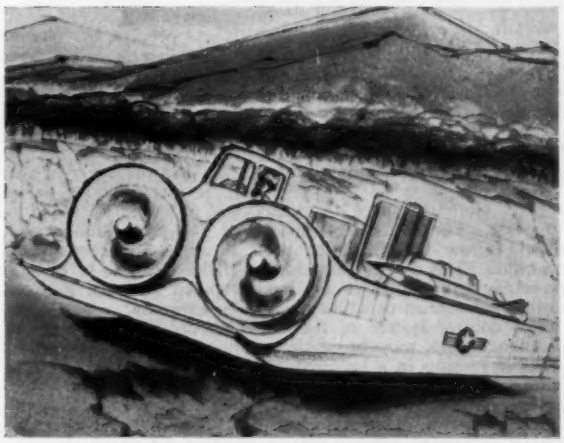
Hover height is 1.8 feet with six passengers for a four-hour mission. Under these conditions, the gross weight is 2,700 pounds. It can hover at 2.2 ft. with four passengers and 2.8 ft. with two passengers. At a gross weight of 2,700 pounds and a height of one foot, the forward speed of the vehicle is 45 m.p.h. At a 6-inch height the maximum speed is 65 m.p.h. The maximum static slope capability at 2,700 pounds is 32 per cent. Cross-country operation in undeveloped areas is possible because of a good slope capability and the ability to travel on

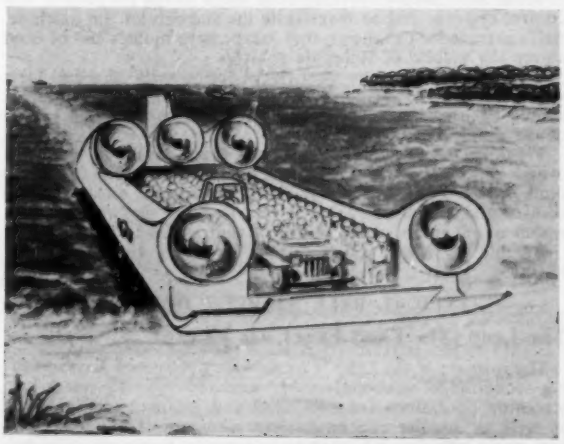
Performance Comparison of GEM Configuration











MILITARY FOURSOME from Bell Helicopters are, top to bottom, the Leap, the Command Car, a Utility Truck and an Assault Troop Carrier.

all types of surfaces. Transition from land to water is accomplished without difficulty.

The Command Car features good controllability, including braking.

One and One-Half Ton Utility Truck

The 1½-ton Utility Truck is used as a supply vehicle to provide re-supply of critical items to forward areas of the battlefield. Due to its high speed and its ability to traverse unimproved terrain, fewer numbers of these vehicles are required in the re-supply mission. It is particularly useful in river-crossing operations and to re-supply and reinforce the beach-head area prior to the establishment of bridging. Once the area is secured, it operates at high overload gross weights over "roads" prepared by simple and quick bulldozing operations.

Power is provided by two 200 h.p. aircraft engines driving 54-inch fans. The cargo desk is 6.5 x 13 feet and can easily accommodate 14 combat-equipped troops. Easy loading is possible because of the low height of the cargo deck.

The vehicle embodies an aerodynamic design which obtains high lifting and forward propulsion efficiencies for economical operation. At the design weight of 5,000 pounds the hover height is 1.4 ft. The maximum slope capability of the vehicle is 30 per cent. A 50 m.p.h. speed is obtained at a 9-inch hover height. Under overload conditions the gross weight can increase to 8,000 pounds. For this case a hover height of 6 inches is possible, and the maximum slope capability is 18 per cent.

Although the Utility Truck is designed to operate over unimproved terrain, additional economies are obtained by traversing semi-prepared roadways. In this manner, extreme overloads can be carried where only low ground obstacles are present.

Assault Troop Carrier

The Assault Troop Carrier would replace and/or supplement LCM, LCVP, and other types of landing craft and amphibian vehicles, in the initial ship-to-shore assault waves. It will also provide a rapid reinforcement and re-supply capability to operating forces ashore, prior to establishment of a well-developed beachhead. Supplemental missions in which this vehicle can be used include river crossings, operations in swamps, flooded estuaries, and other non-navigable terrain.

This craft is 33 x 80 ft. in size, allowing a low base loading to minimise the water depression beneath it. It provides good hovering height capabilities over the mean water surface. Ample deck surface is available for low density cargo. The ATC has a forward facing loading ramp. One engine or five smaller aircraft piston engines are used to provide 2,000 h.p. to drive five fans. If five engines are employed, an aerodynamic balanced stator system would automatically close and seal off an engine's inlet in the event it became inoperative. The roll and pitch control is powerful enough to correct for the resulting asymmetric air supply.

A useful load of 30,000 pounds is carried at the design gross weight of 50,000 pounds. At this weight the hovering height is 2.8 feet and the maximum slope capability is 15 per cent. Speeds of 65 m.p.h. are possible at a one foot height. When required, the craft can decclerate momentarily to obtain maximum height. An inward-folding front permits slicing through waves with minimum longitudinal acceleration. Since the Assault Troop Carrier is of the controlled flow configuration, it has no base plate or bottom. Only large waves would impact on the undersurface to produce vertical accelerations. Operational techniques would be developed to permit beaching in heavy surf. With the good manoeuvrability of the ATC it would be possible to follow a breaker into shore. On the return trip the empty craft would be able to hover at a height of 7 feet.

VICKERS HOVERCRAFT PROGRAMME ANNOUNCED

Vickers-Armstrong (South Marston) is one of three British companies with a strong aviation background now developing ground effect machines. The firm considers the essential concept to be exploited is the amphibious vehicle with a high overwater speed

THE BASIC DESIGN of the first generation of these craft comprises a primary structure in the form of a stiff platform, taking the distributed pressure of the air cushion on the bottom surface. Fans lift engines, and distribution ducts for the peripheral jet are mounted on this platform, with the remaining area providing accommodation for passenger cabins and/or cargo holds. Controls are provided to stabilise the craft in heave, pitch and roll, and to counteract the effects of side loads and yawing movements. Model tests have been made, over water, ground and in the wind tunnel, to determine the aerodynamic behaviour and ground interference effects. To follow up these tests a research craft, the VA-1, was built.

This was fitted with bare essentials only for the first overland tests, and in this condition it first became operational in 1960. It has a weight of 3,300 lb. and an operating height of 4.5in.

It has been operated continuously since with various modifications, including several different lift curtain systems. Stability devices, such as compartmentation of the cushion and associated controls, have also been developed. Various fairings and a cabin have now been added as protection for over-water trials. These modifications have increased the weight to 3,500 lb. and the operating height is now 4.1in.

Since it is recognised that practical demonstration, particularly overseas, is essential with such a new type of vehicle, the next craft has been made sufficiently small to be airfreighted to demonstration sites.

VA-2

The VA-2 is a small utility vehicle, carrying four or five people, with a speed of 40 knots and an endurance of 1½ hours. In addition to demonstrations in remote parts of the world and route assessments for prospective operators, the craft has immediate applications as a fast executive transport over sheltered and inland waters and for the transport of personnel and equipment over difficult terrain where existing types of vehicles cannot operate.

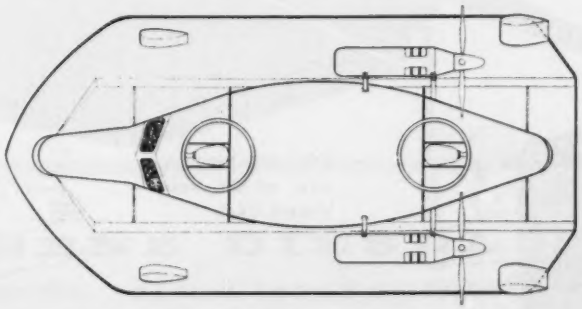
To provide the required width for loading into current British transport aircraft, three sections on either side of the main structure are detachable. To give height clearance for loading, the two fin and rudder assemblies, and complete propulsion unit with support struts, are detachable. They can be rapidly assembled on remote demonstration sites.

The vehicle is powered by three light aircraft piston engines, two for lift and one for propulsion, and the operating height over a solid surface is 8.5in.

Overall dimensions of the assembled craft are: length 28ft. 4in., breadth 14ft. 10in., height 10ft. 4in.

VA-3

The next craft, designated VA-3, is already under construction. This is a 10-ton vehicle and will carry a useful load. As a passenger ferry it can operate in river estuaries and similar terrain, where its amphibious capabilities allow it to operate over water with waves up to 2ft. and over shoals and mudbanks.



VICKERS VA-3, a 10-ton craft designed for operation in river estuaries.

VICKERS HOVERCRAFT PROGRAMME ANNOUNCED . . .

In this role the cabin is fitted to accommodate 24 passengers and crew. For survey, exploration or patrol, the craft can be fitted with a cargo area and could then carry some 4,000 lb. of equipment plus crew for 80 nautical miles at high speed.

The structure design follows the same principles as already outlined, and a similar lift system is employed.

Four Blackburn Turmo-turbine engines are specified for the lift fans and propulsion drives, but the design is sufficiently flexible to permit the use of alternative power units.

For the propulsion system, two reversible, variable pitch, four-bladed propellers are used. The pitch change provides reverse thrust which is used for braking the craft and to aid manoeuvrability.

In addition to the directional control provided by the propulsion system, cable-operated control surfaces on the port and starboard coamings provide effective "keel" area to prevent drift and to assist in turning.

The overall dimensions of the assembled craft are: length 52ft. 6in., breadth 25ft. 0in., height 17ft. 9in.

Future Projects

A great deal of advanced scheming has been done at South Marston on hovercraft of the deep-sea-going type. For the type of seas likely to be encountered on unprotected waters, craft with sizes from 100 to 1,000 tons are being considered. Such sizes are dictated by two factors:

First, for open water operation all through the year, the wave conditions require larger craft with greater operating height. This is to keep the structural loads and power requirements to reasonable values. The second factor, which derives from the relationship of cushion area to perimeter, leads to improved economy of operation, in terms of ton miles per horsepower installed. This is due to the relative saving in power and the greater disposable load in the larger craft. Thus the larger ranges required for open-sea journeys become economic in terms of fuel to payload ratio.

For operation closer to the surface, both overland and over waves, the development of flexible structures is receiving attention. The structure of an air-cushion craft is largely dictated by the impact loads. In the first designs, adequate clearance was provided by having higher powered lift systems, since the structural penalties in designing for greater impact are prohibitive. By introducing flexible skirts the major design limitations are overcome. Local impacts and abrasion are not borne by the main structures, but by the flexible components. These can be designed to accept high accelerations, and thus the accelerations and loads transferred to the main structure can be greatly reduced.

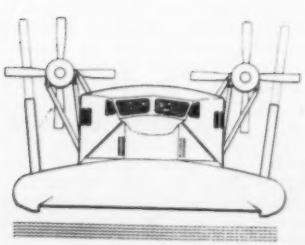
The projected developments described are a long way off in terms of engineering. Although flexibility in its simplest form is already being tried in the form of rubber sidewalls or skirts, the ultimate servo-actuated mechanical device may take ten years. A similar time-scale is likely for the large sea-going craft, and with its great capacity for work, its application to progressively widening markets is foreseen. However, an economic size short haul passenger car ferry is considered much nearer attainment and Vickers are working on a number of such projects.

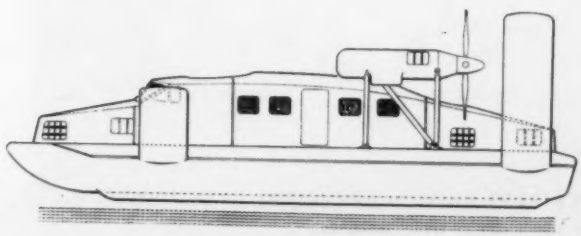
VA-4 Ferry Craft

An early scheme for a craft of around 100 tons has been projected as type VA-4. This craft, with an operating height of up to 3 feet and capable of speeds between 70 and 80 knots, can be an economic proposition.

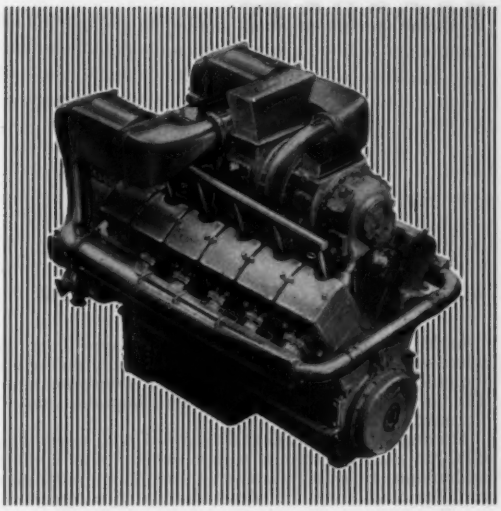
The dimensions of Type VA-4 are: length 173 feet, beam 58 feet. The equipped weight is 61 tons, and the fuel and payload weight is 49 tons.

A number of features may be changed for particular requirements, but at the moment the craft is designed to operate a frequent, high-speed service to off-shore islands in more sheltered seas and channels. To provide manoeuvrability in restricted waterways the propulsion engines are mounted amidships and given mechanical means of deflecting thrust. The bows and sidewalls and the configuration of air cushion are suited to the expected waves, floating debris or solid obstacles likely to be encountered. Emphasis on ferrying cars or other cargo and speed of turn-around will govern the design of doors and hatches. Side versus end loading for the hold is another operational feature to be evaluated.





Side and head-on view of the new Vickers VA-3.



FACTS SPEAK FOR THEMSELVES

... and the facts behind Mercedes-Benz Diesel engines are impressive evidence of their quality. Nearly all the world's hydrofoils, for example, are equipped with Mercedes-Benz: and these high-duty vessels demand a propelling unit which combines unusually high horse-power with a lightweight, compact design. These, of course, are the precise qualities of the MB 820 Db and the reason Mercedes-Benz Diesel type vessels of the more conventional type have also discovered the qualities for its popularity. Other of the MB 820 Db.

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PRODUCTS

DENISON STARTING AND APS SYSTEM

Light weight, reliability, availability played their part in the selection of an engine starting and auxiliary power system for the H.S. Denison. The system selected is designed and built by The Garrett Corporation's AiResearch Manufacturing Division, Phoenix, Arizona.

Driving the system are two modified AiResearch dual power CTCP85 small gas turbine engines developed as aircraft ground and airborne APUs. Grumman familiarity with AiResearch turbines dates from the bleed air CTC85 turbine installed as auxiliary power aboard Grumman's Gulfstream turbo-prop aircraft.

Services provided aboard the hydrofoil by the AiResearch system include: pneumatic main engine starting; electric power generation; compartment air conditioning; compartment heating; snow and ice removal; motoring of main turbines for maintenance and for fresh water flushing.

These engine units are modified versions of the CTCP85-91, currently in production for commercial airline use. The -103 marine version mainly differs from the -91 in the replacement of magnesium compressor housings with aluminium to avoid salt water erosion. This change adds only about 15 lb. to the turbine's normal 260 lb. dry weight.

The CTCP85-103 can produce singly 116 lbs./min. of bleed air (154 shp) as a pressure ratio of 3.34 : 1. Power is delivered from the turbine in two forms—pneumatic and shaft.

Turbine bleed air is manifolded to the system, controlled by a series of AiResearch load control and check valves. For main engine starting this bleed air is delivered to either of two AiResearch air turbine starters, one mounted on the J-79, and another on the T-58 prime mover turbines. These starters are again AiResearch production commercial airline units, also incorporating aluminium for former magnesium components.

Bleed air from the auxiliary turbines is also manifolded to an air cycle air conditioning unit manufactured by Garrett's AiResearch Los Angeles facility. Air is also delivered to ports on either side of the crew cabin, where it may be extracted for snow and ice removal. Operation for the turbines and the entire system is controlled from the craft's "flight" engineer panel.

AiResearch has found the low weight and high reliability requirements of both aircraft and "water flying" hydrofoils to be almost identical. Based on the expected success of the Denison, further work in the hydrofoil system field is already under way at AiResearch.

HYDROFOIL RADAR SYSTEM

One of the world's fastest hydrofoil services is that between Trieste and Venice, a distance of 80 miles by sea. Societa Aliscafi operate this on a twice-daily basis with a Rodriquez-built Supramar PT 20. Leaving Trieste at 7 a.m. on the first run of the day, passengers arrive in Venice in time to start a full day's business, the scheduled time for the eighty miles being two hours.

To aid the Master in poor visibility, the Freccia Dell Adriatico is now fitted with Kelvin Hughes 14/9 radar. The compact dimensions of this equipment make it particularly suitable for hydrofoils and the neat arrangement on the PT 20's bridge is seen above.

MATCHED FAN-DUCT-POWER SYSTEM FOR GEM RESEARCH

The first completely matched fan-duct-power plant system for GEM research has been built by the Garrett Corporation's AiResearch Manufacturing Division, Phoenix, Arizona, for the U.S. Navy's David Taylor Model Basin, near Washington, D.C. It will serve to provide complete design parameters for air handling systems associated with future operational ground effect machine (GEM) vehicles.

Announcement of this contract is the first disclosure of a broad GEM programme conducted at Garrett's Phoenix plant over the past two years. Current work there includes study of systems for GEMs to 100-feet in diameter.

The AiResearch GEM system uses a high performance fan to provide data flexibility through a system of accurately variable blades and stators.

Powered by a 150 shaft horsepower AiResearch small gas turbine engine, the unit's 33-inch fan supplies over 60,000 cfm of air through a matched diffuser and 90 per cent bend. Overall engine-fan-duct system efficiency is better than 81 per cent.

FIRST EXPERIMENTAL LEVACAR to use rails for guidance has as a passenger Dr. Andrew A. Kucher, Ford vice-president, Engineering and Research. Closing the canopy is David Jay, Levacar project manager.

Some of America's leading railways are looking to the Ford Motor Company's Levacar as a possible means of travelling at speeds up to 500 miles m.p.h. between major U.S. cities.

LEVACAR PROGRESS

THE LEVACAR CONCEPT is the brainchild of Dr. Andrew A. Kucher, vice-president, engineering and research, Ford Motor Company, who recognised many years ago that the limiting factor for speed in ground transportation is the wheel.

To overcome this limitation, he proposed a principle of "levitation" that permits vehicles to glide on a thin film of air at speeds higher than those attained by wheels. Now being developed under his direction at the Ford Research and Engineering Centre in Dearborn, Michigan, the Ford Levacar is envisaged as a multi-passenger coach capable of providing public transportation on rails for medium distances from 100 to 1,000 miles, at 200–500 m.p.h.

In this intermediate range, man has used buses, subways, elevated railways and trains. Trains have provided the most satisfactory transportation over these distances, but they are rapidly being left behind in favour of the car and the aeroplane. The Levacar may change this trend.

Among the American railroad companies showing keen interest in the Levacar's possibilities are New York Central, the Pennsylvania Railroad and the Santa Fe. Two of the senior engineers from the Santa Fe have been assigned to work with Ford in exploring the many details involved in the location and design of primary track construction for operation of such a vehicle and other matters relating to the practicability of applying this principle to railwway operation.

The advantages of the Levacar system are these. Since it rides on the ground it will be safer than air travel, because most failures will permit the vehicle to slide to a stop. Because it is readily adaptable to simple automatic control, it is substantially independent of the weather. The anticipated power consumption compares favourably with other modes of transport at these speeds, and the construction cost of a simple lightweight track system is certainly lower than that of comparable roads.

A number of test devices have been built that establish the technical feasibility of the Levacar. To demonstrate the principle on a small scale, two externally-powered working models have been built. The slippers on these models are assemblies of a number of levapads that provide both support and guidance for the vehicle, and their configuration is quite similar to slippers intended for use on full-size vehicles.

To better evaluate the potential of Levacars as a means of transportation it was necessary to design full-size models. The first objective was to design a four-passenger test model capable of travelling at about 250 m.p.h. The first approach was to seat two passengers side-by-side in each of two rows. The vehicle was to be propelled by a turbo-prop engine operating an open propeller at the rear. The resulting study was not too promising, since it was evident that the configuration of the vehicle did not conform with sound aerodynamic design. Its large frontal area as well as its unfavourable length to width ratio increased the aerodynamic drag beyond expectations.

A more satisfactory package was developed by seating four passengers in tandem. The fuel tank was located in front of the passengers with both engines located towards the rear. Propulsion was accomplished by a seven-foot diameter. three-bladed propeller powered by a 397-horsepower turbo-prop engine and air for levitation was produced by a 201-horsepower gas turbine compressor.

A significant innovation in this package was that the rails were located above the bottom of the vehicle to minimise the overturning moment on curves. By placing the level of the rails sufficiently close to that of the centre of gravity, the necessity for banking the track was eliminated, and the vehicle was capable of travelling around curves up to its design speed without any banking whatsoever.

The seating room was developed on the basis of maximum

LEVACAR PROGRESS . . .

comfort. Low "bucket" seats were provided with sufficient leg room for all passengers and an entry opening was provided by a canopy that tilts to one side. A seating buck was then built to test both seating comfort and entry and egress.

Though many configurations of track were considered, a hollow square with six-inch external sides and a wall thickness of .25 inches proved to be the most satisfactory, while the supports necessary for these rails proved to be rather simple, inasmuch as the individual vehicles, even when projected to 40-passenger dimensions, were still quite light. For rail installation it would be satisfactory merely to sink I-beam posts in concrete blocks, space these with pre-cut pieces of angle iron and attach the rails with prefabricated brackets. It appears that the cost of this method should be relatively economical as far as both materials and labour are concerned.

The slippers designed to ride on this rail are equally simple. The main frame is a steel pipe and serves both for structural support of the vehicle and to distribute the levitation air to the levapads. The main component of the slipper is a frame attached to the vehicle frame by a pair of torsion bars and a pair of shackle-coupled, double-leaf springs. These torsion bars and springs allow two directions of motion on the slipper, permitting it to adjust to any irregularities in rail alignment. Each of the levapads is mounted on pairs of pivots, allowing the levapad to change its position relative to the slipper frame to adjust for irregularities in the rail. The air is fed to the levapads through flexible tubes from the vehicle frame. Levapads are provided on the top surface of the rail for support and on the side surface for guidance. Under the rail a strip of brake material is attached to the slipper frame as a safety pad which does not contact the rail normally but is merely present to prevent possible derailment.

Stopping of Levacars will be accomplished by first slowing the vehicle from its maximum speed by reverse thrust. After the vehicle speed has been brought below 100 miles an hour, brake shoes on the slipper are engaged. These are merely attached to bellows and supported by a drag link, and when air is fed to the bellows they expand, and the load is transferred to the brake shoes from the levapads so that the resulting friction causes the vehicle to stop. Heating of the brake shoes is minimised because the heat is not accumulated in the rail but is left behind as the vehicle slides ahead.

To keep the lateral acceleration on passengers below the established tolerance of one g necessitates a minimum track diameter of 1.59 miles equal to a length of five miles. The shortest test track sufficient for design speed would be a circle, and straight runs would have to be in addition to the required five-mile length.

For a better picture of an actual full-size Levacar and the problems entailed, the design of the Levacar X-2 was projected to a 40-passenger vehicle. The passenger comfort standards for this vehicle were maintained at levels established for the Levacar X-2, but the interior was expanded to match the facilities of luxury airliners.

The design of the Levacars clearly indicated that they would have to be specifically designed for particular missions and that probably several distinct and dissimilar types of operations would be needed. The vehicles described thus far were particularly adapted to travel between cities located 300 to 500 miles apart. For very short runs, for instance, between cities located 90 to 100 miles apart, these vehicles would not carry a sufficient number of passengers; on the other hand they would have a maximum speed substantially too high. It was therefore decided to develop a design for a vehicle capable of carrying 200 passengers with a maximum speed of 150 miles per hour.

The package developed for this vehicle included a variety of significant innovations. The length became a serious problem and a double-deck arrangement of seats was necessary. However, to maintain an aerodynamic shape for the vehicle, the end sections could not accommodate this double-deck arrangement, and the tri-level seating arrangement evolved. The exterior dimensions of the Levacar were limited by the usable cross-section of existing railroad tunnels, which prompted the use of two propellers, one at each end of the vehicle. By combining this feature with flip seats, the vehicle became capable of operation equally well in either direction and could be considered for initial installation on a single-track system without turnarounds.

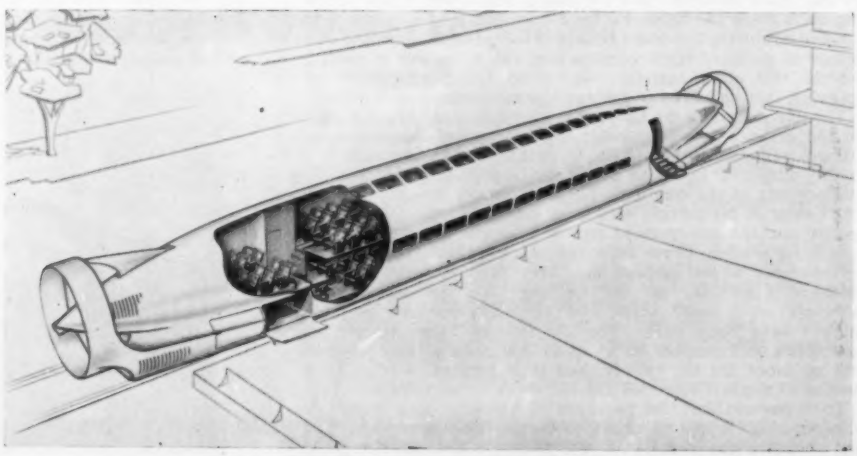
Travel in the Levacar X-5 between cities located 90 miles apart would require only 38 minutes, though acceleration would take three minutes and deceleration two minutes, the excess over full-speed travel time (36 minutes for 90 miles at 150 miles an hour) is only two minutes, since the entire travel is only 38 minutes. Allowing time for loading and unloading, operation on a single track could easily be carried on a one-hour schedule. Of particular interest is the comfort of the passengers during acceleration and stopping, for the maximum acceleration is felt during stopping and this is only 1/14g.

It is of interest to note the low power required for propulsion; it would take only 162 horsepower for the vehicle to maintain a speed of 100 miles per hour on level ground. The 1,300 horsepower recommended for the Levacar X-5 would propel the vehicle at 200 miles per hour on level ground and at 150 miles per hour at a 2 per cent grade.

The speed for which this vehicle was designed is low for Levacars and so the power required for levitation is large as compared to that required for propulsion. Levitation would require about 2,100 gas horsepower, and guidance on a straight run about an additional 300 horsepower. For travelling round curves, it is suggested that provision be made to withstand 1/2g lateral acceleration by providing controls to feed air only to the side at which it was needed. Acceleration of 1/2g is obtained on a curve of 3,000-foot radius or about 2 degrees of curve in railroad terminology. Total provision for 3,500 gas horsepower is sufficient.

It has been suggested that the cost of an initial Levacar installation might be more acceptable if a first track installation could be made on an existing rail line. Unfortunately, existing rails are completely inadequate for Levacars, and design of a Levacar to ride on conventional railroad tracks is not feasible. However, they could be used as the base for Levacar tracks and a simple attachment bracket could be made.

No inference is intended that operation of Levacars substantially on the ground is recommended. For a permanent installation, an elevated structure seems to offer many advantages and will probably prove quite economical; because of the light weight of the individual vehicles, the entire overhead structure for Levacar rails will also be very light.



LEVACAR X-5 will have two propellers, one at each end. By combining this feature with flip seats, it will be capable of operation equally well in either direction and could be considered for initial installation on a single-track system without turn-arounds.

GROUND EFFECT MACHINE

DATA SHEET No. 1

The Westland Aircraft

(Saunders-Roe Division)

SR.N2

General Description

The SR.N2 is a 25-ton to 35-ton hovercraft designed primarily to obtain operational experience which will assist in the development of future commercial craft. The layout is designed round a central load-carrying area to permit easy control of the C.G., regardless of the size and shape of the payload.

A buoyancy tank is incorporated so that the craft may float on water, and the bow shape has been designed primarily for over-water operation.

Structure

Typical aircraft methods of construction have been used, primarily to achieve low weight, the principal material being high strength aluminium clad aluminium alloy with protective treatments.

Areas subjected to noise will be made of aluminium-faced plastic foam-filled sandwich construction.

The basic structure is a composite beam formed by the ogival-shaped buoyancy chamber, the deck above the air duct, and the main passenger cabin. This arrangement provides a rigid beam in bending and torsion.

The buoyancy chamber is divided into 15 watertight compartments, and also contains two 425-gallon fuel tanks laterally disposed and two 100-gallon water ballast tanks for fore and aft trimming.

Passenger/Freight Compartment

The 20ft. x 16ft. cabin has seating capacity for between 54 and 66 passengers, depending on the degree of comfort, or for 100 standing troops. Luggage storage is provided beneath the fan air intakes. Alternatively, two large cars or one lorry fully loaded can be accommodated. The cabin side and top panels are removable to facilitate stowage of large freight items.

Engines and Transmission

The layout consists basically of two large fans and two reverse pitch propellers. The fans supply pressurised air for lift and the propellers drive the craft and enable it to manoeuvre. The system is powered by four Blackburn A.129 free-turbine engines, each rated at 815 h.p. at their maximum continuous rating, housed in pairs in an aft engine room well away from the main cabin. Each pair of engines is coupled to one fan propeller combination. The shafting for the forward units passes through the central cabin roof beam.

Controls

The craft is controlled solely by means of the two high-mounted propellers. Movement in the desired direction is obtained by varying the pitch of the propellers and swivelling them laterally on their pylons up to $\pm$ 30°. The electro-hydraulic system governing the propellers is operated through a directional controller located in the pilot's cabin.

Ground Handling

Under normal conditions the craft will be serviced on a hard standing, and six steel pads are incorporated into the structure around the outer edge to provide resting points.

All normal maintenance, loading and refuelling will be carried out on land, although if desired the craft could be moored like a boat.

A three-wheeled handling chassis has been designed for manoeuvring the SR.N2 on the ground. It has port, starboard and rear units which are attached to the craft by quick-release pins; built-in hydraulic jacks are extended when the units are in position. The units are buoyant so that the chassis can be used from a mooring, or in the event of an emergency such as an engine failure.

Maintenance

Removal and installation of the fans has been facilitated by making the structure above the fans detachable as a single assembly. The engine room cowlings are removable for *in-situ* maintenance and engine charging.

Summary of Principal Features

Overall length	60ft. 3in.
Overall beam	29ft. 6in.
Power Units	4 Blackburn A.129 Free-Turbine Engines.
Normal Internal Tankage	850 gallons
Typical Operational Weight of 59 passengers or 2 military vehicles version	27 tons.
Range	200 nautical miles
Cruise Speed	70 knots
Cruising Height	1.0–1.5 feet
Max. Height at light weight	2.5 feet

WORLD'S FASTEST SAILBOAT is the Baker Manufacturing Company's Monitor, built for the U.S. Navy. Capable of speeds in excess of 30 knots, it is more than 5 knots faster than the fastest catamaran.

HYDROFOIL SAILBOAT

THE HYDROFOIL SAILBOAT Monitor flies twice the speed of the wind with the bottom of the boat, at top speed, almost three feet above the water. A ride in the Monitor begins like one in an ordinary sailboat with the hull in the water. When the Monitor reaches about 12 knots the slap of the waves against the bottom suddenly stops as the hull climbs free of the water. At speeds in the range of 30 knots the boat is riding on only the tips of its three stainless steel hydrofoils. The only sound is that of the wind in the rigging and the swish of the hydrofoils slicing through the waves. The tension in the rig is very high because the boat speed produces a relative wind of gale velocity and the hydrofoils permit very little heel.

The Monitor was designed by the Baker Manufacturing Company of Evansville, an organisation which began manufacturing windmills in 1873 and has continued in the water system business to the present time. The company became interested in hydrofoil development before World War II and just after the war made a proposal to the U.S. Navy to do research on hydrofoils for military purposes. When the proposal was rejected, the company turned to civilian applications for hydrofoils. It directed its attention to the development of a hydrofoil sailboat because this appeared to offer the best opportunity for a large increase in speed with hydrofoils. A model towed behind a motor-boat was an early step in the company's sailboat development. The next step was the construction and testing of a 16-foot sailboat with three V-shaped surface-piercing hydrofoils. As a third stage in the development of hydrofoil sailboats, the company designed the Monitor and constructed all but the hydrofoils.

Because the cost was higher than expected, the project was postponed in favour of the development of a hydrofoil system for 14-foot motorboats. This development was finished just before the Korean War. The boats have three V-shaped extruded aluminium foils. Steering when flying is done by means of the forward hydrofoil with the motor straight. The hydrofoils enable the boat to ride about a foot above the water, resulting in a smoother, faster ride and increased manoeuvrability. They can be folded up for shallow water travel, docking, and land transportation. With a 10 h.p. motor the boat has a top speed of over 30 m.p.h., 27 m.p.h. carrying four men.

After a trial manufacture, the company decided to discontinue production of the hydrofoil outboard motorboat because of an anticipated material shortage due to the Korean War and again approached the Navy with a proposal to do hydrofoil research. On the basis of the Navy's examination of the hydrofoil outboard motorboat, a contract was awarded under which two hydrofoil research craft were designed and constructed. Both used the same hull design and propulsion system. The first, named High Pockets, is 23 feet long with four V-shaped aluminium surface-piercing hydrofoils. The second, named High Tail, has three fully submerged angle controlled hydrofoils. Both go about twice as fast as a conventional boat with the same horsepower.

By arrangement with the Navy, the hydrofoils for the Monitor were finished at Navy expense in return for their use of the Monitor for test purposes. The Monitor's hydrofoil system consists of three surface-piercing ladder foils, two forward and one aft. Steering is done by rotating the rear foil

Hydrofoil Sailboat . . .

about an upright axis. The Monitor is believed to be the world's fastest sailboat. She attains her best performance in winds from 13 to 18 knots.

Hydrofoils offer more of an advantage to a sailboat than they do to a motorboat. The reason they do is that the propulsion thrust of a sail increases with speed while the maximum obtainable thrust from a given engine decreases with an increase in speed through the water. In a beam wind of a given velocity an increase in sail speed by a factor of four increases the maximum obtainable thrust about 1.5 times. (This holds as long as the sail speed is not over four times the wind speed.) By contrast, an increase in speed of a motorboat by a factor of four with the same engine means a reduction in the maximum obtainable thrust to about one-quarter.

The increase in propulsion thrust of a sail with speed is well demonstrated by iceboats. In a 10-knot breeze, for instance, it may be necessary to push an iceboat to get it started, but once under way it may skim over the frozen surface at 40 knots. It is for this reason that the ratio of potential gain in speed due to reducing forward resistance by the use of hydrofoils is much greater for the sailboat than for the motorboat.

Unfortunately, if the maximum propulsion thrust is obtained, the sail side force—the components of the resultant force on the sail perpendicular to the course—increases by a much larger factor than that by which the forward thrust increases. At high speed the side force and resulting rolling moment under the condition of maximum propulsion thrust become so large that the lateral spacing and area of the hydrofoils needed to counteract them would be too great to be practical.

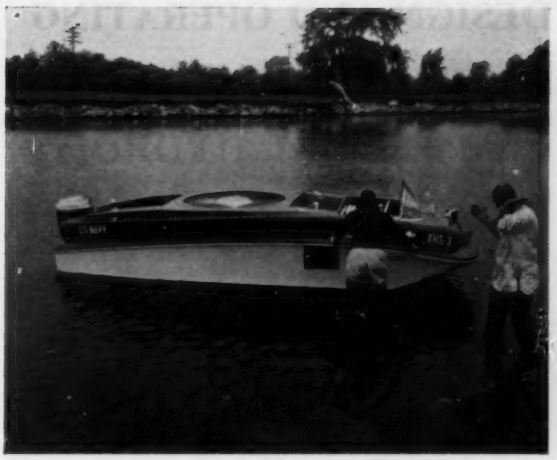
Fortunately, once a hydrofoil sailboat has attained enough speed to become foil-borne, she no longer needs the maximum thrust of her sail to keep her flying. By using a flat sail, trimmed to spill some of the wind, a skipper can fly his boat without rolling the lee foils under. Even with this reduction the forces on the sail are enormous, because during flying the relative wind reaches gale velocities. With a canvas sail it is difficult to maintain a proper sail shape, and considerable effort is required to trim the sheets. For these reasons a rigid sail appears desirable, if the problem of cost and transportation over land could be overcome.

In addition to supporting the boat, the hydrofoil system of a flying sailboat must, of course, sustain all reactions of the sail not supplied by the weight and the weight distribution of the boat. The ability of the hydrofoil system to counteract the high side force of the sail depends (1) on the projected area of the hydrofoils in a vertical plane parallel to the keel and (2) on the type of hydrofoil configuration.

The rolling moment produced by the side force acting at the centre of area of the sail can be balanced partly by shifting weight to windward, but the main reliance must be on the difference in submergence and angle of attack between the windward and leeward hydrofoils. The magnitudes of these differences depend on the lateral spacing and the type of hydrofoil.

SPEED COMPARISONS

Type of Boat	Name	Knots	Date	Source of Information
American Cup Boat	Yankee	13.5	1931	Communication from Yachting Publishing Corp., N.Y., N.Y., Sept. 19th, 1955.
Clipper Ship	Sovereign of the Seas	17.7	About 1854	"Clipper Ship Days," by John Jennings, published by Random House, N.Y., N.Y., 1952.
Catamaran	—	25.0	1952	"World's Fastest," Life Magazine. Aug. 25th, 1952, Vol. 33, Page 55.
16-foot Flying Sailboat	—	20.0	Before 1952	Comparison with a motorboat with a known speed-tachometer relationship.
Flying Sailboat	Monitor	26.1	Sept. 1955	Comparison with two different motorboats with known speed-tachometer relationships.
		30.4	1956	Comparison with University of Wisconsin motor lifeboat, which has a known speed-tachometer relationship.



BELL'S HYDROSKIMMER

GROUND EFFECT MACHINES have been called a variety of names, but that preferred by the U.S. Navy's Bureau of Ships is hydroskimmer, since, obviously enough, it gives the craft a sea-service identity.

The Bell Aerosystems Company's (formerly Bell Aircraft Corporation) research craft illustrated above is built under a Bureau of Ships contract and is therefore a hydroskimmer. It is one of four craft built for them for testing during 1960/61. Two others in this programme were built by Hughes Tool Company, one featuring two side skegs and fore and aft waterwalls, and the other a total waterwall, and one, a completely peripheral jet craft, was built for the U.S. Marines by National Research Associates.

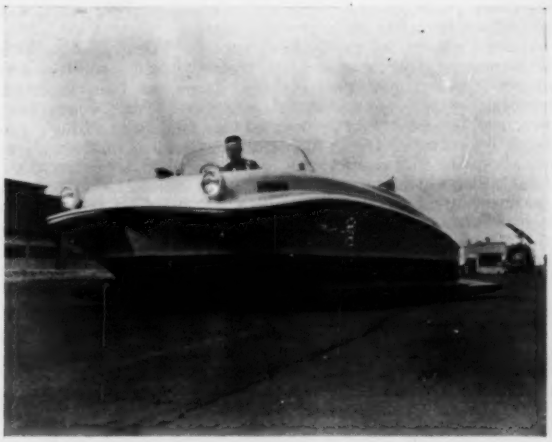
The Bell craft is an 18ft. long sidewall vehicle with air walls fore and aft. It has an 8ft. beam and weighs 2,300 lb. Levitation is provided by a 75 h.p. Porsche mounted horizontally amidships, and propulsive power by an 80 h.p. Mercury. Speed of the craft is given as 30 knots. The hull is of fire-retardent polyester resin, reinforced with fibreglass.

The evaluation testing of this craft covers handling characteristics, internal air flow and base pressure, and thrust and drag versus speed measurements.

Handling characteristic tests were to include assessments of three types of skegs—knife edge, ship shape and planning; range of nozzle angles and thicknesses; range of speeds with full, partial and no airflow; turning radius and acceleration runs.

In February 1961, Bell Aerosystems demonstrated publicly a test vehicle, built with its own funds, that is similar to the U.S. Navy craft. The craft showed its ability to pivot in its own length, hover and perform conventional forward, backward and turning manoeuvres.

Prior to the demonstration, the craft was given a special New York State licence plate bearing the letters "ACV," making it the first air cushion craft licensed for operation on state roads. It is shown below.



DESIGN AND OPERATING PROBLEMS OF COMMERCIAL HYDROFOIL BOATS

by Baron H. von Schertel
(Supramar A.G., Lucerne)

OUR COVER PICTURE SHOWS SIRENA, one of the Supramar PT 50 hydrofoil boats plying between Stockholm and the Finnish Aland Islands. Equipped with two Daimler-Benz diesel engines of 1,350 h.p. each, the Sirena seats 120 passengers.

IT HAS TAKEN a comparatively long period of time (some 50 years) to develop the hydrofoil boat into a type of craft now commercially applied as a "new" means of transportation. By comparison, development or airplanes, roughly starting at the same time as that of hydrofoil boats, proceeded at a very much faster pace. Indeed, the airplane has now reached a very high degree of perfection, while interest in and development of hydrofoil craft have not been steady over the years. One reason for slow progress in the art of "flying" in water may have rested in a number of hydrodynamic problems, not encountered in air. Even after solving such problems, a number of well-performing experimental boats were simply disregarded, however. It appears that the new means of waterborne transportation was considered with suspicion; and practical application was prevented by the tendency of ship owners and operators to stick to the traditional, conventional and conservative types of boats and ships.

It was only during World War II that the perfection of hydrofoil boats was seriously approached, both by hydrodynamicists and by the boat-building industry. After that war it was realised that high-speed craft of this type would be economically feasible, and that they could, in proper application, compete operationally with modern land- and air-borne means of transportation. Necessity or desire was also acknowledged in recent years to adapt the speed of transportation on water, as far as possible, to the general level of our fast-moving age.

Not until the last 10 years could one see practical proof, however, of the fact that so many years of effort and research have finally produced hydrofoil boats of an operational character. Regular commercial services of reasonable passenger-carrying capacity have been introduced in those years; police and similar authorities have found fast hydrofoil boats to be particularly suitable in their operations. It seems, therefore, that the advantages of this "new" type of water-borne transportation, predicted and explained so often over the years, will be utilised hereafter on a growing scale.

Quite a number of papers have been published, dealing with development, physical principles, hydrodynamic problems and various types of hydrofoil systems. Little has been reported, however, regarding commercial operation. The present text, therefore, is predominantly devoted to a discussion of the place which hydrofoil craft can fill within the field of modern transportation. In this regard, conditions of particular interest are those under which hydrofoil boats can or should be used. Such conditions are derived from practical results of operations such as mentioned above. Theoretical considerations are presented to the extent as they seem to be important in the evaluation of operational characteristics.

The Demand for High-Speed Transportation on Water

The first practical consideration is the need or demand that exists or may develop for an increase of speed in water-borne transportation. At the beginning of the 19th century, ships were, no doubt, the fastest means of long-distance transportation. Around the turn of the present century, development of land-borne vehicles (railroads) was already far advanced. Since then, aircraft have been perfected to such a degree that today more passengers cross the Atlantic by air than by ship. This indicates that most people prefer speed (saving time) rather than relaxation while travelling. Such preference for speed is particularly evident in short-distance trips across water, wherever means of transportation speedier than the conventional water-borne type are made available. Examples for such situations might be lakes (or Long Island Sound) or boat lines on rivers (or along the coast) or, last but not least, ferry services such as to and between islands.

After the arrival (availability) of reliable hydrofoil craft, another change seems to develop within the short-distance sector of water-borne transportation. Because of their high cruising speed, up to three times as high as that of previously existing conventional boat lines, foil-supported craft appear quite capable of competing even with fast land-borne vehicles (wherever such competition is geographically possible). For example, regular hydrofoil-boat service and experimental trips along the coast of Italy have demonstrated that these boats (proceeding on straight course) can reach certain destinations in an appreciably shorter time than land-borne vehicles (railroad trains or automobiles) which of necessity follow the more or less jagged line of that coast, forced to go around numerous bays. Other natural opportunities for the application of hydrofoil boats are found across lakes or bays and between islands (or between mainland and islands, of course).

Transportation to and between islands can also be provided by *aircraft*. A certain minimum distance is required, however, before such transportation would be more economical than that by boat or ferry. Hydrofoil craft may successfully compete, however, with airplanes, even over longer distances:

(a) on the basis of their comparatively high speed level,
(b) because of considerably lesser cost of operation and maintenance,
(c) if considering their place-to-place, rather than airport-to-airport performance.

Conditions of transportation may, in other words, be thus that, after boarding a hydrofoil boat, the passenger arrives at his island destination in less time than when going to and from airports and flying a short time in between.

Over short distances, the helicopter might be a serious competitor of hydrofoil craft(combining somewhat higher speed with superior manoeuvrability). Here again, and likely more so than in conventional airplanes, the cost (per passenger) of operation and maintenance would be very much higher for the helicopter than for the hydrofoil boat. Conditions can thus prevail where the use of hydrofoil boats in particular is much more economical and preferable all around over any air-borne means of transportation.

Experience in various types of modern transportation proves not only that passengers generally prefer to travel, and are willing to pay for travelling at high speed—but saving time when travelling is also an important consideration in tourism as such. Provided that they can cover a larger distance in a given period of time, people will presently undertake longer trips,

such as, for example, a certain round trip within a day's or a week-end's time. A man, commuting to and from work, forced to go or given the opportunity of going by water, would most likely take the fastest boat available. The time consumed in going to and from the place of work is also very important to employer or company; namely, under conditions where compensation must be paid for that time. Such is, for example, the case in off-shore oil-drilling operations, where skilled mechanics, operators and maintenance crews have to be carried over considerable distances. Not only is the time needed to get these passengers to and from the drill rigs costly—it is also very desirable that boats used for such trips have favourable riding (seakeeping) qualities, so that the men do not get tired and worn out merely from travelling. It is proposed that for such applications, hydrofoil boats are the most suitable means of transportation.

Besides passenger services, there are a number of other uses for hydrofoil craft, where speed is of primary concern. Boats in this category are important in military (Navy), rescue (Coast Guard), police and similar operations.

Suitability of Hydrofoil Boats in Commercial Transportation

Scheduled passenger service by means of water-borne craft becomes commercially interesting:

- on the basis of speed comparable to that of land-borne vehicles,
- under the condition that the service can be made profitable,
- provided that service can reasonably be maintained in bad weather.

The suitability of hydrofoil boats with regard to such conditions is considered as follows.

Speed and Economy

Foil-supported craft can be designed for comparatively high speeds, and they can operate at such speeds with reasonable efficiency. This is to say that at higher Froude numbers (or speed-size ratios) hydrofoil systems are known to function at drag over weight ratios below those of conventional motorboats (either of the planing or of the non-planing type). In conclusion, hydrofoil boats must be expected to be comparatively economical (as far as size of machinery and fuel consumption is concerned) in certain size and speed ranges where other types of water-borne craft cannot very well operate effectively.

In Figure 1, the specific power requirements of various water and aircraft are plotted against speed, and this permits the calculation of the performance of a hydrofoil boat in comparison to that of a hard-chine (planing-type) craft. On the basis of equal size and equal power, it can thus be found, for $V(D/W) =$ constant, that maximum or cruising speed of the foil-supported craft must be expected to be approximately 50 per cent higher than that of the planing type of boat. Such prediction has been confirmed by full-scale trial runs. In August 1943, a 52ft. "KM" boat of the German Navy (with 2×700 h.p. engines) was, for example, tested in competition with a hydrofoil craft built to the same dimensions and equipped with the same engines. The latter reached a maximum of 47 knots while the "KM" boat could make only 30 knots. In a different test, a 32ft. hydrofoil craft was run first as such, reaching 31.3 knots. The same boat (having a stepped-bottom hull) was subsequently tested in planing condition, i.e. after having taken off the foil system, and using a propeller permitting utilisation of equal power. Speed was only 21.4 knots in the latter case.

The graph (figure 1) also indicates that the V-bottom planing type of craft requires approximately twice the propelling power of a same-size, same-speed hydrofoil boat. As an example, we may consider a craft with a displacement weight of 28 tons and a cruising speed of 36 knots. Comparison in terms affecting operational economy is as follows:

for type of boat:	foil-supported	planing type
power to be installed ...	1,350 h.p.	2,700 h.p.
number of passengers ...	75	38

The conventional V-bottom type is to be credited with a reduction of structural weight (by 4.4 ton) because it does not have to carry a foil system. However, doubling the propeller power requires an additional machinery weight of 7.1 tons (assuming a unit weight of 11.7 lb/h.p., including fuel sufficient for a range of 300 km.). Taking also into account some material necessary to strengthen the planing bottom, the dead weight of this craft is then expected to be at least 3 tons higher than that of the hydrofoil boat. The equivalent loss of passengers (on a weight basis) is in the order of 37. The number of paying passengers is, in other words, reduced to $\approx$ half, while the expenses for machinery and fuel are roughly doubled. Experience in commercial passenger transportation proves that, applying the foil-supported type of carrier, a yearly net profit can be obtained in the order of some 40 per cent of capital invested. On the other hand, using the planing type of boat, no profit can be expected at all under the conditions of operations as stated above.

(to be continued)

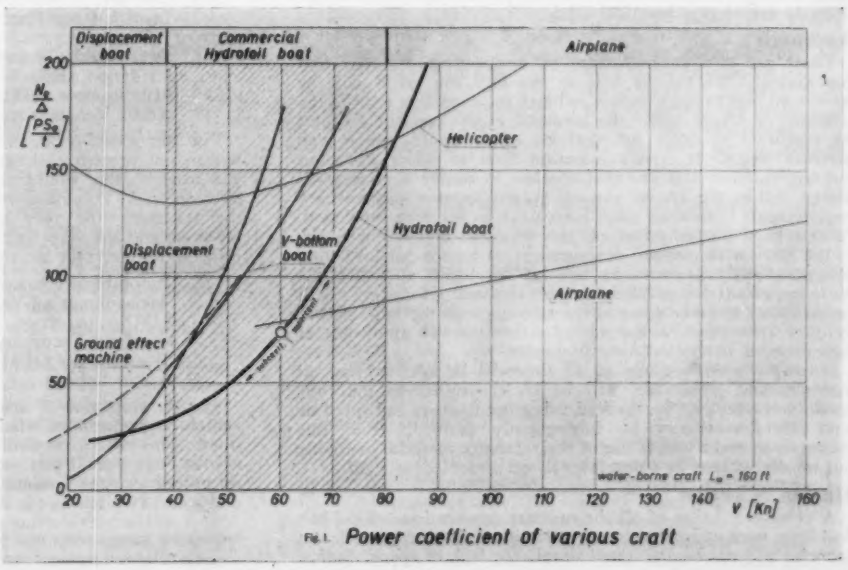


Fig. 1. Power coefficient of various craft

A GEM FOR AMPHIBIOUS SUPPORT

by
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Introduction

During the past two years the state-of-the-art in GEM's has progressed from little more than a few concepts developed from fundamental theories to research vehicle planning based on experimental evidence and sound engineering evaluations. Many models and man-carrying machines have been built and tested and we now feel confident that it is time to make the next step to the 60-foot craft. Various areas of research will need continued study, but it is expected that the GEM will now move rapidly into the development stages. For example, and as will be developed in this paper, we know now how to optimize dimensions and power requirements for a specific mission and can spell out design characteristics for vehicles of a practical size.

Design studies and some component procurement can be expected to commence in the immediate future. Research studies to fill the gaps in our knowledge of GEM's should continue through 1965 and results of testing programmes on initial vehicles will then dictate the rate of progress as regards future operational GEM's.

We are not going to discuss other people's "work in progress" or the state-of-the-art as a separate entity, but rather, we will sum up significant developments to arrive at conclusions on areas needing further work by actually presenting a short design study to arrive at a practical GEM.

Approach

There are two general areas of application—military and commercial. We believe that in the U.S. the GEM will be developed first to meet certain military requirements for specific missions of a type where the potential of the concept can best be exploited to do a job that no other single vehicle can perform today. It is our intention then to select a certain military mission and for this mission to derive a conceptual design within the known state-of-the-art to meet the military requirements (unofficial since none have so far been set down). After a brief discussion of military missions and our selection of the one for conceptual development, at least a partial listing of operational requirements will be developed and then the more important design characteristics derived. Obviously it will be necessary to make some of the selections on the basis of our military knowledge on the subject rather than anything that is well founded in the technical literature.

Attempts will be made at all times to be specific and all numbers and efficiencies will be clearly stated so that our resultant values can be checked using the theories indicated or any others that may be subsequently derived. It is our intention to make liberal use of the reference material available but no derivations or formulas will be presented as such.

Mission Selection

A complete listing of all the military applications of GEM's that have been suggested to the various services or government agencies will not be attempted simply for lack of space. Suffice it to say that there are a huge number—a number of them proprietary concepts that we are, of course, not free to discuss. From the first, however, there has been a great deal of consistency in the thinking of the principal investigators and government sponsors of the research programmes to define primary objectives. It must be realised that the dictates of the several services will vary considerably and where it appears that there is some overlap, this occurs only on minor details. For example, the requirements of the Army for a Logistics Over the Shore (LOTS) Carrier and those of the Marines for an Amphibious Vehicle are extremely close, with only the specifics of performance or design philosophy or operational characteristics to result in compromises to a single design to meet both missions. With this in mind then, here are the mission concepts to be considered with an indication of the government agencies expressly interested:

1. Amphibious Support Vehicle—USMC, BuShips.
2. Anti-Submarine Vehicles—BuWeps, BuShips.
3. Reconnaissance Vehicle—Army Transportation Corps.
4. LOTS Carrier—Army Transportation Corps, USMC, BuShips.
5. Casualty Evacuation Craft—N.Y. Port Authority, Army T.C.
6. Overland Troop and Weapons Carrier—Army T.C.
7. Load Lifting Platforms—Naval Supply Centre, Army T.C.
8. Ocean-going Transport—BuShips, BuWeps, MarAd.
9. GETOL—Army T.C., BuWeps.
10. Minesweeper—GEM-BuShips, Army T.C.
11. Arctic Vehicle—Army T.C.

For our exercise we will select an application reasonably within our present abilities—i.e., a vehicle that falls within a size category that would be the next logical step in the natural development. This rules out several on our list at both ends of the spectrum—the very small vehicles for very specialised missions and the very large vehicles that would make the next jump too large. Out list then is shortened to:

1. Amphibious Support Vehicle.
2. Anti-Submarine Vehicle.
3. LOTS Carrier.
4. Overland Troop and Weapons Carrier.
5. Minesweeper GEM.
6. Arctic Vehicle.

The development of specialised equipment necessary for a vehicle to perform its mission at all is not within the task outlined. This would probably be necessary on items 2, 5 and 6 above. Item 4 we'll rule out because of the lack of information on precise control systems that will be required for operations overland. This leaves the Amphibious Support Vehicle and the

* *Extracted from a paper read by the authors to the U.S. Society of Automotive Engineers International Congress, 1961.*

LOTS Carrier—as pointed out above, both with very similar mission requirements. Almost everyone who has studied the GEM field and considered their possible vehicle applications is attracted by the amphibious aspects of the concept. For our task we'll choose the Amphibious Support Vehicle because of the obvious Marine and Navy interests of the authors.

Amphibious Support Vehicle—Mission Requirements

A careful appraisal of the transport shipping that is presently available to carry the Amphibious Support GEM to the operating area narrows considerably when the dimensions of the craft are projected to carry a respectable payload. Since, for the foreseeable future, we must tie out ship-to-shore amphibian to our transport shipping to form a system or team, perhaps we first should look at just what is available in the LSD or LPD area and determine the optimum dimensions for the GEM from the standpoint of maximum shipping payload that can be carried with reasonable efficiency. We will start by taking the Thomaston Class LSD and matching various GEM planforms to its well-deck dimensions. Fig. 1 shows the well-deck dimensions of the LSD in plan and side views. Starting with the smallest size vehicle that can carry a usable payload (given enough power) and then rounding overall dimensions to fit as well into the LSD as possible, we arrive at the five GEM planforms shown in Fig. 2.

In order to select one of these on which to develop design characteristics it is first necessary to look at the performance capabilities and cost analysis of all of them. This was accomplished by solution of performance equations and a tabular cost analysis derived from weight and power requirements. Only a summation of this information is presented since a complete design will be developed later.

Table I.

Size—De (Ft.) ...	32.7	39	50	56.7	63.5
Payload (Tons) ...	3	5	15	25	40
Horsepower (Total)	2,000	2,700	4,400	7,000	11,300
Est. Cost ($) ...	.15M	.3M	.5M	.8M	1.4M

The above figures were developed for annular jet type GEM's with costs estimated on the basis of gross weight and power plants presently available. Recirculation schemes with their lower power requirements will reduce the cost figures considerably. However, on the basis of what is now known, the above are believed to be reasonable. It can be seen that the two smaller vehicles have HP/Ton payload ratios in the same range as existing helicopters with total payload figures well within present helicopter capabilities. And, whereas the very high payloads of the two larger machines are certainly attractive, the handling problems of loading and unloading from the parent shipping and the fact that overall height of these machines would eliminate the possibility of stacking, it is therefore apparent that the GEM as a compatible member of the amphibious team will fall in the 50-foot class.

Fif. 3 is presented to show a possible stacking arrangement with the 50-foot GEM.

With our dimensions chosen, then, Fig. 2, we will attempt to develop all the other performance and design specifications for our Amphibious Support GEM. First, some thoughts on speed —or cruising velocity. Present vehicles can move over unimproved land surfaces at from 5–15 knots. Generally speaking, a vehicle that moves well in the water makes a very poor land craft and vice versa. Because of the large planforms expected to just lift our GEM payload, we know that in order to justify our machine in the first place we must offer large improvements in certain areas. One obvious one is speed. An order of magnitude increase in speed is attractive from the viewpoint of those who have worked so long with vehicles in the 5-knot class. Just what will a 60-knot-plus cruising speed mean to our Amphibious planners: (1) it will allow the transport shipping to move further out to sea from the objective area and to disperse in depth and breadth, (2) timing can be more closely controlled and specified, (3) the option of running parallel to beaches and selecting one's landing site is enhanced, (4) vulnerability is considerably decreased and an enemy's decision-making time greatly shortened. These and other advantages accrue from a large increase in speed alone.

In order to assure a better than 60-knot cruising speed overwater in sea conditions in which present-day craft can and do operate, just how far above the surface will our GEM have to operate? Landing craft operating in the open sea and making the ship-to-shore transit rarely can tolerate sea states higher than 3: i.e., 3–4ft. waves (trough to crest), 10–15 knot winds and a 6ft. plunging surf. Amphibious operations are carefully planned. Based on long-range forecasts, they are usually carried out under much more favourable conditions. The ideal situation, therefore, would be to have a vehicle with a 2-foot cruising height just barely skimming over the tops of the waves on the way to shore and a trade-off in power to enable the machine to slow up and cruise at a higher height to get through the surf. On this particular point there seems to be large differences of opinion. First of all, between the people now actually designing GEM's, and secondly, between the philosophy of certain GEM designers and conventional ship construction people. The two schools of thought on GEM design are: first, that very low planform loadings should be used and the vehicles should operate clear of all waves over water and all obstacles overland; and second, that high planform loadings and structural strength be incorporated so that the vehicles can operate at minimum heights consistent with the ability to maintain speed, occasionally knocking off the tops of waves or bumping ground irregularities. Ship designers and hydrodynamists are quick to point out the very high wave impact loads imposed on hulls operating at high speeds. However, results reported on GEM models operating in wave systems indicate considerable attentuation of impact loads due to the presence of the air cushion. In other words, this cushion acts as a pneumatic suspension system as though it were an integral part of the vehicle. It therefore seems entirely reasonable to accept lower cruising heights and bull your way through wave crests in order to improve payload capability.

Present amphibious vehicles have payload capacities in the range of 5 to 15 tons, so if a 15-ton payload can be achieved as indicated in Table I, then our GEM will be at least a stand-off from the payload point of view.

LIST OF SYMBOLS

Vehicle Parameters

b — beam in feet.
C — perimeter of base in feet.
D_e — equivalent diameter in feet.
G — nozzle width in feet.
l — length in feet.
S — base area in square feet.
W_c — crew weight in lbs.
W_e — empty weight in lbs.
W_{eng} — engines, fans and power system weight in lbs.
W_f — fuel weight in lbs.
W_g — gross weight in lbs.
W_p — payload in lbs.
β — tangential jet deflection angle in degrees.
θ — normal jet discharge angle in degrees.

Performance and Design Parameters

C_{lo} — aerodynamic lift coefficient.
C_{df} — parasite drag coefficient.
D — net drag in lbs.
D_f — parasite drag in lbs.
D_{ram} — ram drag (momentum drag) in lbs.
h — height above surface in feet.
L — total lift in lbs.
P — total power ($P = P_c + P_p$).
P_c — cushion-system power in lb-feet per second.
P_p — propulsion system power in lb-feet per second.
δ_p — free stream dynamic pressure in lbs/ft.
T_j — thrust component of jet reaction in lbs.
V_j — average jet velocity at discharge in ft/sec.
V_o — free stream velocity at discharge in feet per second.
$\triangle_p$ — cushion pressure in lbs. per square foot gage.
η_a — augmentation efficiency.
η_d — duct efficiency.
η_f — propulsive efficiency.
η_{int} — internal efficiency.
η_p — compressor efficiency.
ρ — mass density of air in slugs per cubic foot.

In summary, then, we have a GEM 36ft. x 68ft. in size with a cushion area inside the jets equal to 1,963 square feet (50-foot effective diameter) with the following performance requirements derived from operational considerations:

Cruise speed—at least 60 knots.
Cruise height—2 feet.
Hover height—3 feet.
Payload—15 tons.

Development of Design Specifications

Besides the operational performance requirements stated above, the only specifications clearly spelled out are the overall restrictions on size imposed by our transport shipping. We have determined overall length and width dimensions from matching with LSD well-deck dimensions and have also imposed a height restriction of 10–12 feet to permit stacking. The question now arises: is it possible to meet the performance requirements within the limits imposed? Our very cursory look, Table I, indicated it was. However, before a more systematic investigation of the individual parameters is undertaken, the following guidelines or conclusions developed from the work of other researchers and proponents of GEM's is summarised:

GEM Types

1. The levapad or air bearing concept will be applicable to only very specialised smooth surface operations.
2. The plenum chamber concept is ruled out as being too inefficient.
3. Recirculation schemes (including the labyrinth seal) offer great potential for the future but require a great deal of experimental verification.
4. The Ram Wing is in an unknown area in which research on fundamental theories are lacking but where possible large improvements in performance can possibly be found.
5. The annular jet offers the most immediate potential.

Sizes

Machines ranging from very small models and toys up to man-carrying vehicles 32 feet long and 30 feet wide have been built and operated.

1. Annular jet GEM's of the order of 60 feet in length and 30 feet wide are now being built in England. The Saunders-Roe SR-N2 has a payload capability of 7 tons at an operating height of one foot at 70 knots cruising speed.
2. It appears that a successful practical GEM with overall length of 50–75 feet should be the next size to be built in the U.S.
3. Vehicles between 100–150 feet in length with GW in the 70–125 ton class could be undertaken in the foreseeable future. This machine could probably compete economically on a commercial basis with existing means of transportation on certain routes.
4. Vehicles larger than 150 feet in length and 150 tons in GW can anticipate severe problems in the structural areas and in carrying its necessary chemical fuel load.
5. Very small GEM's (<20ft. D_e) appear to present a more severe development problem.

Shape

Although the shape of the machine will be dictated to a great extent by the mission application, the following general comments apply:

1. Vehicles with length to beam ratios in excess of 2.5 : 1 suffer unacceptable losses in lifting efficiency and present serious roll stability problems.
2. The internal aerodynamics of circular and oval shapes are simpler as regards ducting and nozzle configuration for machines with a central air inlet.
3. Some type of pointed bow appears necessary for operation over water in a wave system to minimise impact loads.

Speed

The attainable velocity over land and water will be a function of the following:

(a) Power used for lift (momentum drag).
(b) Profile drag of the body configuration.
(c) Power installed for propulsion.

1. Maximum speed for any particular configuration will be achieved by operating as close to a perfectly smooth surface as possible.
2. Until high speeds (greater than 50 knots) are reached, speeds over water will always be lower than for the same machine over land—due to frictional drag of water spray and the higher lifting power (thus higher momentum drag) requirements over water.
3. Speeds in excess of 50 knots should be reached only when it is known that no obstacles are on the flight path or no waves will be encountered.

Operating Height

The attainable operating height will be a function of the following:

(a) Power installed for lift.
(b) The planform area contained inside the jets.
(c) The jet thickness and jet velocity.
(d) Angle of inclination of the jet.
(e) The gross weight of the machine.

1. Without special provisions for stability or excessive power for lift, it appears that GEM's will be constrained to always operate at h/D's below 12 per cent to be competitive with developed transportation vehicles.
2. GEM's should always operate at minimum heights consistent with safety to maximise efficiency and economy.
3. Cruising heights of the order of 2–5 per cent appear presently reasonable with maximum hover heights (full power) at 10–12 per cent.

A great many other items could be spelled out with some assurance of acceptance from those now working in the field. However, a great many of these will be developed more completely in what follows, so that a mere statement or conclusion at this point would be redundant. All of the above conclusions and many not listed were kept in mind throughout the study.

Performance Analysis

With machine overall dimensions selected, a rough performance check using data from reference 2 was made for various speeds, weights and operating heights. For this first pass, the following assumptions were used:

$\eta_a = 0.73$	$C_{lo} = 0.30$
$\eta_p = 0.80$	$C_{df} = 0.05$
$\eta_t = 0.80$	$W_{eng} = 2.5$ #/HP
$\eta_d = 0.70$	$R = 200$ n.m.
sfc = 0.6 fuel/HP hr.	$W_{crew} = 1000$ #
$W_s = [6 + .00067 (W_g - 40{,}000)]$ #	

The efficiencies listed above are those shown in reference 2, and were used here initially to permit direct extraction of data. Two modifications were made, however: (1) A lift coefficient of 0.30 rather than zero was used, and (2) the resulting values of horsepower required were reduced by ten per cent because it was felt that the overall efficiency assumptions were somewhat conservative. As will be seen later, the analysis is strongly influenced by these assumptions of efficiency, and even the altered values used in this part are probably conservative.

From these data, curves of equivalent lift-drag ratio, and payload ton miles per horsepower hour, were prepared for values of gross weight between 40,000 and 70,000 pounds in 10,000-pound increments, and at speeds between zero and 100 knots. These curves are presented in Fig. 4 and Fig. 5. With the assumptions used, it is seen that there is a small reduction in equivalent lift-drag ratio and in payload ton miles per horsepower hour, with increase in gross weight up to about 60 knots. At higher speeds, however, the heavier machines tend to become more attractive. For example, at a speed of 100 knots, equiva-

lent lift-drag ratio is virtually independent of gross weight between 40,000 and 70,000 pounds at the cruising height of interest.

At cruising speeds near optimum there is a degradation in performance with increasing gross weight, but this effect is substantially smaller than had been anticipated.

To obtain a preliminary insight into power requirements, curves of total power versus speed were also prepared. These data for the three higher weights are shown in Fig. 6, and are for a height of 3 feet at hover and slow speed, and a cruise height of 2 feet. It appears from this last figure that the most severe power requirement will be for the 3-foot hover and slow speed case. Initial thoughts on configurations with power plant arrangement for reasonable usable cargo space indicated that four engines might be desirable. The rough data indicated that a machine with four 1,200 h.p. engines would have the desired performance at close to 60,000 pounds. Consequently, preliminary design points of 3 feet at hover and slow speed, and 2 feet at 90 knots were selected for a gross weight of 60,000 pounds. A somewhat more careful analysis was then begun in the vicinity of these design points. It was also decided that efficiency assumptions somewhat different from those used in reference 2 would more nearly reflect current capabilities, and consequently the following were selected: $\eta_s = 0.76$, $\eta_t = 0.83$, and $\eta_d = 0.73$. It is very probable that these values are still too conservative, but they will be used in all subsequent calculations unless otherwise noted.

It was first necessary to select some more geometric characteristics. Plots of jet discharge angle versus h.p. at hover were prepared for three values of nozzle width, using Chaplin's simplified engineering analysis from reference 1. These curves are shown in Fig. 7. A θ of —70° was selected quite arbitrarily and was used to check several values of G at cruise condition. About the widest nozzle that could be operated with reasonable values of tangential jet deflection angle at the cruise condition turned out to corresspond to a nozzle width parameter of 0.3 giving a G of 0.79 feet fixed, a curve of θ versus h.p. at hover was recalculated taking into account the direct jet lift. This curve is also shown in Fig. 7 and indicates that although a θ of —70° is very nearly optimum, no significant penalty is paid for slightly reducing this angle. Since a smaller absolute value of θ should result in lower turning losses, a θ of —60° will be used in all further calculations. In addition to altering the optimum value of θ, the direct jet lift also causes a significant reduction in power required, particularly at the higher operating heights. To simplify the analysis, this term will be neglected in further calculations except the final one. It should be borne in mind, however, that powers are overstated to the extent that this direct jet lift term is neglected.

With θ and G chosen, a more complete investigation of the design cruise condition was made. Here again, Chaplin's simplified engineering analysis was used. Separate propulsion power required is determined by the combined contributions of three force terms: ram drag, parasite drag, and the thrust component of jet reaction. These longitudinal force terms are plotted versus speed for the two-foot cruise case in Fig. 8. Cushion power required is determined by the combined contributions of three pressure terms: effective cushion pressure, jet dynamic pressure, and free stream dynamic pressure. These three pressure terms, modified to the form that they have in the equation, are plotted against speed in Fig. 9. These data are provided merely to indicate the relative magnitude of the various terms which determine P_c and P_p. Actual power versus velocity curves are shown in Fig. 10. The large dependence on both P_c and P_p on β is clearly shown. The effect of β on total power is not as marked. A cross plot of Fig. 10 at constant speed in the vicinity of the design cruise point is shown in Fig. 11. Because of the relatively small effect of β on total power, initial consideration was given to selecting a fixed value of β which would be a reasonable compromise between the optimum values of $\beta = 0°$ at hover, and $\beta = 26°$ at a speed of 90 knots. This could be done with a total power penalty of less than 10 per cent, and the cost and complexity of variable vanes in the peripheral nozzles could be avoided. However, the very strong influence of β on the ratio of P_c to P_p offers a powerful device for propulsion system matching. The most significant effect of variable β is associated with the fact that effective nozzle area is reduced as β is varied in either direction from zero. This causes an increase in cushion power by increasing jet dynamic pressure, and a decrease in propulsion power by providing a longitudinal component of jet reaction. This longitudinal component of jet reaction can be thought of as partially cancelling momentum drag. Another method of controlling the ratio of cushion power to propulsion power is to use variable width peripheral nozzles. Here again the effect on total power is small, but the effect on the ratio between cushion power and propulsion power at cruise is quite large. An advantage of being able to vary nozzle width is that the optimum setting can be used at hover. The hovering power reduction, however, is only about three per cent from the value required with the compromise nozzle width of 0.79 feet used previously. The fixed nozzle width chosen is optimum at about 62 knots, and about 30 per cent too wide at 90 knots. Being able to reduce nozzle width to the optimum setting at 90 knots would result in a power saving of less than two per cent. This should be compared with the power saving at cruise of nearly ten per cent obtained with a fixed G and variable β. Another advantage of variable β is that it can be used for directional control. This should be particularly advantageous at slow speed. Either system could be used for pitch and roll control or trim, and it is possibly these considerations which will make the incorporation of one system or the other mandatory in any practical machine intended for rough surface operation.

The selection of a two-foot cruise height, which has been used in the previous section, was predicated on operational considerations. It is obvious that a lower height would be used if the sea condition permitted. Because of this, an off-design overload condition was considered. Several possibilities were checked, and speed-power curves for three values of β are presented in Fig. 12 for a 90,000 machine cruising at a height of one foot. For this case, equivalent lift-drag ratio increases to 7.4, and payload increases to 54,000 pounds. Summary plots of equivalent lift-drag ratio and payload ton miles per horsepower hour are presented in Figs. 13 and 14 for the two cruise conditions considered.

The machine defined for the 90,000 pound overload case is not exactly the same as the 60,000 pound machine, in that a structural weight estimate of 7.34 pounds per square foot was used for the lighter machine, and 9.35 for the heavier. Consequently, in this case, if the 60,000 pound machine were designed to have the overload capability indicated, a structural weight penalty of approximately 4,000 pounds would be incurred. It seems clear from this that some degree of overload capability should be designed into the machine. This is particularly true in the case of the amphibious support vehicle, where a strong requirement exists for a vehicle with a large payload to projected area ratio. It had previously been thought that the shortcomings of the GEM in this respect were inherent in the concept. Present non-amphibious landing craft, such as the LCVP and LCM, have payload to area ratios ranging from about 20 pounds per square foot to about 90 pounds per square foot. This compares with a payload-area ratio of about 13 pounds per square foot for the 60,000 pound GEM and 25 pounds per square foot for the 90,000 pound GEM. The situation is changed somewhat if current and anticipated amphibious landing craft are considered. In this case, the ratio of payload to projected area is in the range between 23 and 35 pounds per square foot. The water speed of these tracked and wheeled amphibious vehicles is much less than the speed of the GEM, in most cases an order of magnitude less. Since the high speed potential of the GEM is well known, the point to be emphasised here is that the payload-area ratio of the GEM overlaps the payload-area ratio of current and projected amphibious vehicles.

If the extremely serious requirement to maximise payload-projected area ratio had been properly evaluated in an earlier stage of this design study, it is clear that a more highly powered heavily loaded machine would have been chosen. The relative insensitivity of gross weight to equivalent lift-drag ratio and payload ton miles per horsepower hour has been referred to and is shown clearly in Figs. 4 and 5. This is merely another example of the fact that the selection of physical characteristics of any machine must be based upon an analysis of the factors which will be used in comparing it with competitive devices. The range of design parameters for GEM's is extremely broad, and mission requirements and the weight assigned to each of these requirements must be clearly specified before an intelligent approach can be made to the inevitable compromises involved.

Effect of Efficiency Assumptions

Any value of a performance analysis such as this one would be greatly increased if the individual effects of all the contributing parameters could be separated. Time does not permit individual consideration of all the variables separately, but it is clear that the entire exercise is quite sensitive to the values assumed for the various efficiencies. It is felt that the ones used are conservative, and one point will be checked with the following set of efficiency assumptions which might be representative of values obtainable for a fully developed, carefully engineered machine:

$$\eta_a = 0.80$$
$$\eta_d = 0.90$$
$$\eta_t = 0.90$$
$$C_{1v} = 0.50$$
$$C_{dt} = 0.04$$

The point checked was the overload cruise condition of 90,000 pounds and 90 knots at one foot. Total power is reduced from 3,380 h.p. to 2,200 h.p., and equivalent lift-drag ratio is increased from 7.4 to 11.3.

Critical Cruise Conditions

In this study a great many factors have been neglected. One of these involves the fact that, at reasonable cruising speeds, jet velocity and vehicle velocity are of the same order. There does not seem to be any reason why jet velocity cannot become less than vehicle velocity as long as jet total head remains greater than free stream total head. However, a different situation obtains as far as free stream dynamic pressure and effective base pressure are concerned. At the vehicle speed where dynamic pressure is equal to base pressure (approximately 84 knots in the 60,000 pound case considered here) the front jet is no longer required if it is assumed that the full dynamic pressure is recovered under the machine. Actually, there may be some flow under the machine; toroidal vortices exist under and around the machine; and the flow is three-dimensional in the vicinity of the pointed bow. Because of these and other factors, the physical realities of the situation when $q_\infty = \triangle_p$ do not seem to be obvious. There are several reasons, other than the previous one, for wanting to close the front nozzle at cruise. Aerodynamic lift on the top surface will probably be centred forward of the c.g.; the main air inlets will almost certainly be above the c.g.; and the main nozzles with their tangential deflection vanes are below the c.g. All of these factors contribute positive pitching moments, the major one of which is probably ram drag on the main inlets. Closing the front nozzles is one way to obtain a negative moment to trim the machine at cruise. A condition which will certainly be critical develops when free stream total pressure equals jet total pressure, but this occurs at much higher speeds than are considered here.

Fan Selection and Design Criteria

In the preceding section the power requirements for the specific design have been determined. The design of inlets, nozzle geometry and duct systems necessary to handle the large mass flows required to achieve successful operation at all conditions are determined by the basic overall internal losses associated with volume flow, exit total head and jet external flow considerations. Most GEM's built to date have incorporated ducted single stage axial-flow fans and, although some thoughts on the use of radial-flow fans will be presented, it is considered that GEM application of the radial type will require far more extensive comparison than is available in the literature today.

It can be shown that the two main causes of internal energy losses are the fan (propeller) losses and the duct losses. Since these vary in opposing manner, it is possible to minimise the overall losses and define an optimum fan diameter. The largest portion of the fan losses is due to the action of the fan blades, whereas duct losses are most commonly associated with size, shape, turns and smoothness of the ducts themselves. Losses caused by guide vanes and fan blade gaps are usually included with the duct losses. Since the overall internal loss in total head can be obtained by adding the fan and duct losses, it is possible to develop an expression that relates the total internal losses to the fan-duct geometry, the total head increase, the shaft rotational speed and the axial flow velocity through the fan. Such an expression is derived in reference 3, so will not be repeated here. From the geometric and performance parameters developed so far, the following power system design criteria are presented:

No. of engines: 4.
H.p. each engine: 1,200.
H.p. max. continuous: 1,000.
No. of fans: 4.
Diameter of fans: 5.8ft.
Hub/tip ratio: 0.6.
Rotational speed: 1,750 r.p.m.

Total power requirements have been divided among four (4) fan-engine combinations in order to reduce the total volume flow per fan, thus lowering fan losses and simplifying duct design. Further reductions and lower losses could be obtained theoretically by going to still more fans, but would only serve to increase internal mechanical complexity. The large hub is required to keep the blades from stalling at the hub. Rotational speed at cruise is derived from the fact that optimum diameter increases continuously as the rotational speed is reduced. Hence, the engineering compromises of (1) space limitation, (2) tip speed compressibility at high forward speeds and (3) power required over the speed range, have determined the fan diameter and the other design characteristics presented.

The selection of engines of the gas turbine type in the horsepower range shown presents the possibility of direct drive to the fans, thus eliminating gear boxes and long drive shafts. The considerations of machine reliability and maintenance would tend to dictate against this type of installation, but, upon reflection, the use of engine-fan modules of the direct drive type offers the capability of a fan-inlet-duct design so suspended in the overall GEM system as to be practically insensitive to external impact loads that the hull structure might receive. Interchangeability of propulsion system components as units and the lower mechanical losses of such a system are also strong factors in its favour. Therefore this system is incorporated, although the disadvantages previously mentioned may prove at some future date to require that actual GEM's of this size employ separate engine compartments and some type of drive not even considered here.

As pointed out in the previous section, there exists a strong requirement for trade-offs in cushion and propulsion power. How this is achieved will to a large degree design our machine. At the three (3) foot hover height 3,900 h.p. is required for the cushion system; at the cruising speed only 900 h.p. is required for the cushion whereas 2,450 h.p. is needed for propulsion. From this it can be seen that if an entirely separate propulsion scheme were employed a total of 6,350 h.p. would have to be installed. Of this total only a small proportion would be used at any one time—a very inefficient way to utilise engines of the expensive gas turbine type. Propulsion system integration allowing trade-offs between the requirements of lift and forward thrust can be achieved in a variety of ways. Utilisation of controllable vanes in the longitudinal peripheral slots has already been discussed.

Separate propulsion power can be achieved by (1) direct jet thrust through controllable exit slots or louvres, (2) shafting from the common engine units to open or ducted propellers in the free stream or (3) combinations of the first two methods.

The decision to split total power required between four (4) engine-fan systems in combination with the above considerations for employing some type of integrated propulsion scheme now requires that placement of our power units be determined. Several other factors must be taken into account at this point: (1) methods of achieving control throughout the speed spectrum, (2) location, size and accessibility of crew and cargo compartments, (3) internal ducting and slot geometry, (4) provisions for ground handling and while used in conjunction with amphibious shipping, (5) structural design features in keeping with mission requirements, (6) floatation and sea-keeping capability while floating and during transition from hover to high forward speed, and many others. To present all the arguments on each side between these factors individually, in pairs and/or combinations would be a complete design study in itself. Therefore, our

decision will be presented and only a few of the reasons for it developed.

The four nacelle units with forward facing multibladed high-solidity fans directly connected to their gas turbine type engines mounted in the fan hub afterbody are placed two on each side of the roughly rectangular planform. Internal ducting employing corner vanes will carry the flow to the peripheral nozzles and the compartmenting slots. Propulsion power will be obtained by (1) shafting from the two rear engines through their nacelle bodies to open pusher propellers on the two aft corners of the vehicle and (2) controllable direct jet louvres on the aft sides of the two front nacelles. The split between the power available on the rear combinations will vary between 300 to 1,200 h.p. for the cushion system and 0 to 900 h.p. for the open propeller propulsion system. These open propellers will be reversible in pitch to provide maximum deceleration thrust and precise control at slow speeds. The controllable louvres on the forward nacelles are placed at the vehicle transverse centre line to provide a maximum side force at this point should it be required. The split between cushion and propulsion power from the louvred jet thrust of the front nacelles will be 200 to 1,200 h.p. for the cushion and 0 to 1,000 h.p. (minus duct and louvre losses) for propulsion. Provisions for closing off the front jet at high forward speeds as δ_0 approaches $\triangle_p$ will reduce the cushion power requirements of the front nacelles as indicated.

Referring to Fig. 10, an example of power utilisation is presented as follows: at hover to maximum height, power is applied to all four engines with propulsion louvres closed (front nacelles) and propeller shafts idling (rear nacelles). At 1,000 h.p. per nacelle the machine lifts to 3 feet with β angle 0°. Control in the hover condition is achieved by adding more power and utilising combinations of the open propellers and the side louvres for turning or positioning at the 3 foot height or by constant throttle position and accepting a slight degradation in hovering height performance and bleeding some small amount of control power as indicated above. Transition to forward flight is achieved by varying the vanes in the longitudinal slots to give a positive β angle and then opening the side louvres of the front nacelles and adding power to the open propellers of the rear engines for optimum forward thrust. As β is increased there will be some small loss of operating height and either additional power must be added or the reduced operating height used. As forward speed is increased, the cushion power requirements decrease as indicated, and the propulsion power required goes up—the split of power available is made accordingly till the cruising speed of 90 knots is reached. As this point is approached the forward jet is programmed closed and the equilibrium condition is such that at the two (2) foot cruising height 200 h.p. per each front nacelle is going to the cushion and 700 h.p. to the propulsion louvres and 250 h.p. per each rear nacelle is going to the cushion and 650 h.p. to the propellers. Since only 2,500 h.p. is needed for propulsion at this cruise condition, 200 h.p. is reserved for control.

Stability and Control

It has many times been stated that GEM's operated at height ratios of less than 5 per cent will be inherently stable, and that compartmentation will raise this neutral stability point to 10–12 per cent. There is evidence, however, from several investigators that cross-flow beneath the base plate of the vehicle under certain operating conditions will tend to make the machines unstable at all height ratios. From this it would appear that compartmenting slots of some type would be absolutely essential and it is believed that stability augmentation of this type is the standard method of approach of all serious designers. The particular design described above and summed up in the following section has an operating height range from 2 per cent to 6 per cent, so it is felt that no special provisions for stability need be made other than the aforementioned compartmenting slots.

There have been several mentions made on how control of GEM's can be achieved. At the present time there exists no firm control criteria for these vehicles. As has been stated, reversible pitch open propellers will be available for braking and slow speed yaw control. The placing of the engines on each side of the vehicle feeding separate peripheral slot sections makes possible roll control by differential throttling and additional pitch control. Side forces can be achieved by directing the side louvres normal to the flight path from either front nacelle as required.

It is recognised that one of the most serious problems facing GEM's is their stability operating over irregular surfaces or wave systems of any kind. There is now just enough information or data on which firm conclusions regarding GEM design for stability, or for that matter, stability requirements or criteria, can be made. It is believed that before any serious programme to build a reasonable size GEM be undertaken, a systematic dynamic model testing programme on specific design should be completed with a large portion concentrated in the area of stability and control.

Design Specifications Amphibious Support Vehicle

As was indicated earlier in this paper, the desired payload of the machine being considered is 15 tons. Most of the data presented in the charts and discussed in the text relates to a 60,000 pound machine which has a payload, using the assumptions of this study, of 28,000 pounds. Some reserve power is available, however, since the 3 foot hovering and slow speed case is considered to be a maximum performance condition for short periods only while negotiating surf or other hazardous surface conditions. The desired payload could be obtained, therefore, by increasing the gross weight to about 62,500 pounds without exceeding the capacity of the installed power. Some characteristics of the machine finally arrived at are presented below:

$b = 36.4$ ft. (overall width 40 ft.).	$S = 1{,}963$ sq. ft.
$C = 180.8$ ft.	$W_c = 1{,}000$ lbs.
$D_e = 50$ ft.	$W_{eng} = 12{,}000$ lbs.
$G = 0.79$ ft.	$W_f = 4{,}500$ lbs.
$l = 54$ ft. average between front and rear nozzles (overall length 68 ft.).	$W_g = 62{,}500$ lbs.
	$W_p = 30{,}3200$ lbs.
	$W_s = 14{,}800$ lbs.
	β = variable, $+45°$ to $-45°$
	$\theta = -60°$.

Ptot = 4,800 h.p.

All of the performance and design parameters used are summarised below. When a specific operating condition is implied it is the cruise design point. It should also be noted that account has been taken of direct jet lift.

$C_{lo} = 0.3$	$P_p = 2{,}350$ h.p.
$C_{df} = 0.05$	$T_j = 2{,}200$ lbs.
$D_f = 2{,}700$ lbs.	$V_j = 154$ ft/sec.
$D_{ram} = 6{,}550$ lbs.	$V_k = 90$ knots
$\frac{LV}{P} = 5.14$	$\beta = 340$
	$\eta_a = 0.76$
$h = 2$ ft.	$\eta_j = 0.73$
$P = 3{,}360$ h.p.	$\eta_f = 0.83$
$P_c = 1{,}010$ h.p.	$\eta_{int} = 0.607$

Conclusions

These, then, are the results of this regrettably superficial design study. It is felt that many of the assumptions made would be extremely difficult to defend, and the writers do not believe that there is a sufficient body of valid engineering data available to successfully undertake such a defence.

There are, however, two general types of conclusion which can be drawn from this study; first, conclusions which result from consideration of the rate of change of certain quantities with others, and the relative significance of some of the factors which should be substantially independent of their actual value; and second, conclusions of a considerably more tenuous nature which might be drawn by examination of the actual numbers used in the study. In the first category the following conclusions are presented:

1. Reasonable GEM's of the size considered here will have optimum speeds approaching 100 knots.
2. A reasonably high speed GEM must have either variable width peripheral nozzles or variable vanes in the peripheral nozzles if hovering performance is at all important.
3. A system must be provided for adjusting the ratio of cushion to propulsion power unless only a very narrow efficient operating range is desired.

Some conclusions in the second category which are sensitive to the actual numbers used in this study are as follows:

1. Equivalent lift drag ratios comparable to those of transport aircraft can be achieved if the surface is relatively smooth.
2. Economic efficiency, as measured by payload ton miles per h.p. hour, should be substantially superior to that of a helicopter, and comparable to transport aircraft at short and medium range.
3. Payload gross weight ratio should be superior to either the helicopter or the aircraft, or to any other known form of high speed off-road vehicle whether amphibious or not.
4. The degradation in performance of a particular size GEM with increase in gross weight is not as large as had previously been thought. This is quite significant in its effect upon the potential application of GEM's in the amphibious support field where a strong requirement exists for machines with a large payload per unit of projected area.

A GEM FOR AMPHIBIOUS SUPPORT . . .

FIG. 1

WELL DECK DIMENSIONS OF THOMASTON CLASS LSD

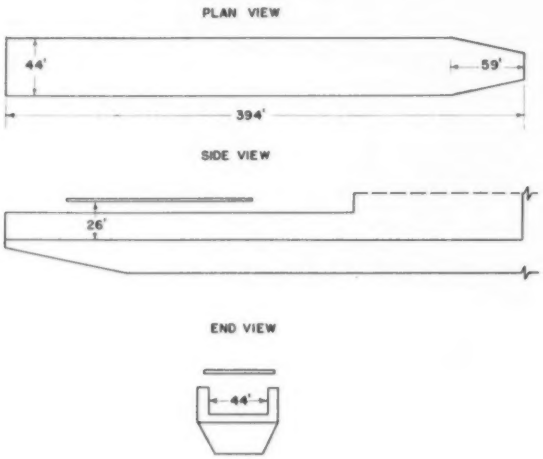


FIG. 2

LOADING PLANS FOR VARIOUS SIZE GEM's

THOMASTON CLASS LSD

WELL DECK DIMENSIONS - 44' X 394'

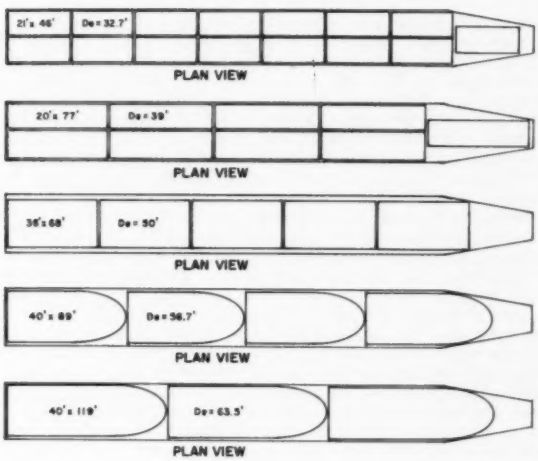


FIG. 3

LOADING ARRANGEMENT FOR

36' X 68' X 12' GEM

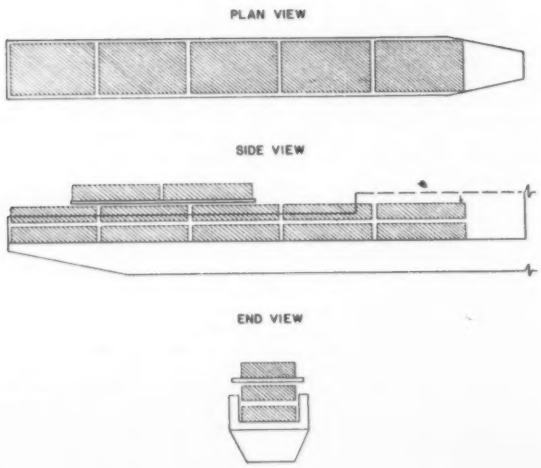
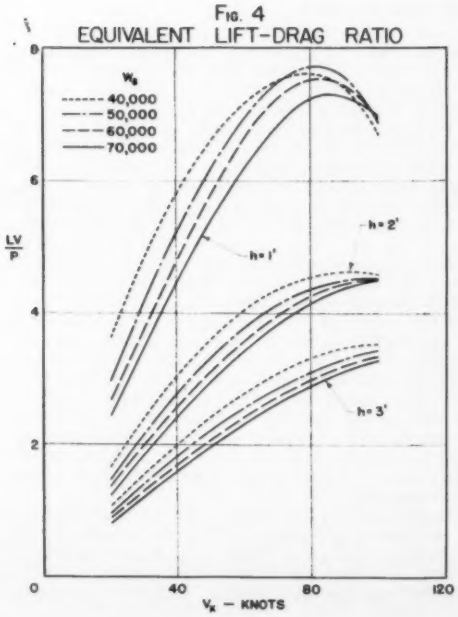


FIG. 4

EQUIVALENT LIFT-DRAG RATIO



A GEM FOR AMPHIBIOUS SUPPORT . . .

FIG. 5
ECONOMIC EFFICIENCY

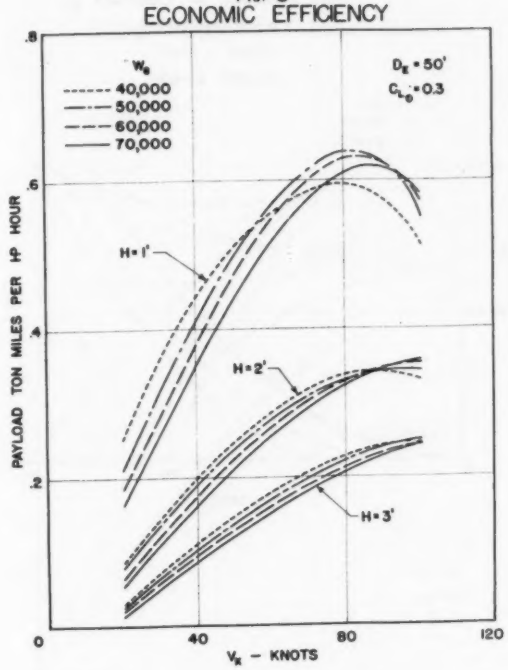


FIG. 6
POWER REQUIRED
D_E = 50' C_{L_o} = 0.3

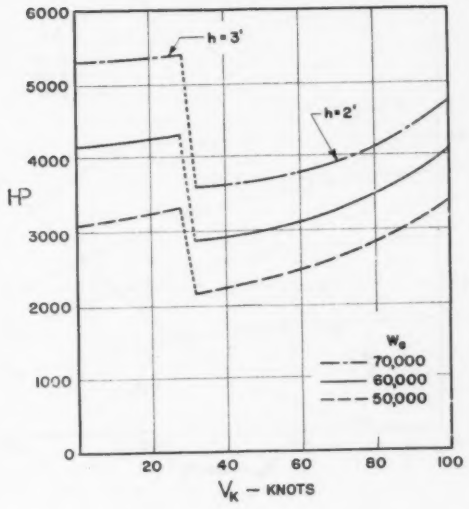


FIG. 7
HOVERING POWER AT CONSTANT G
W_o = 60,000 LBS. D_E = 50' h = 3'

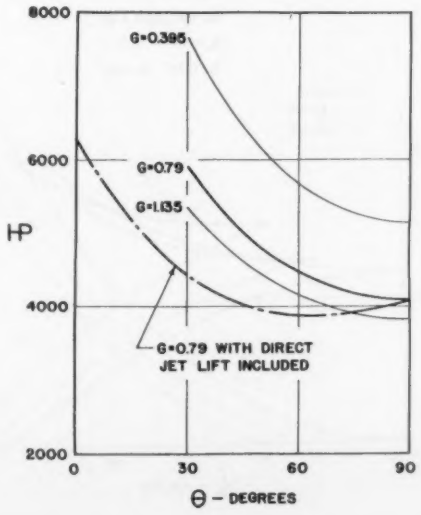
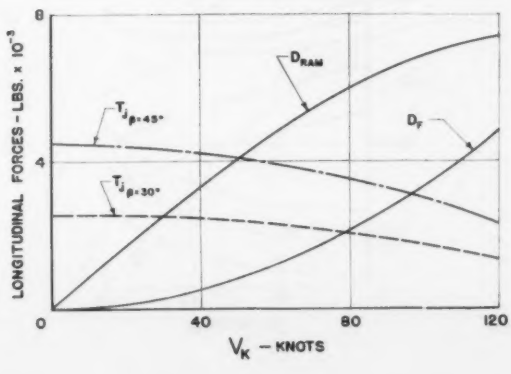


FIG. 8
PROPULSION POWER COMPONENTS
W_o = 60,000 LBS.
D_E = 50' h = 2' θ = -60°



A GEM FOR AMPHIBIOUS SUPPORT . . .

FIG 9
CUSHION POWER COMPONENTS
W_G = 60,000 LBS.
D_E = 50' h = 2' θ = -60°

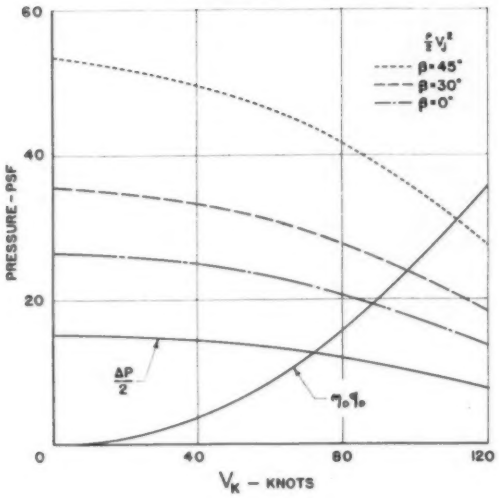


FIG. 10
POWER REQUIRED AT CONSTANT β
W_G = 60,000 LBS.
D_E = 50' h = 2'
G = 0.79' θ = -60°

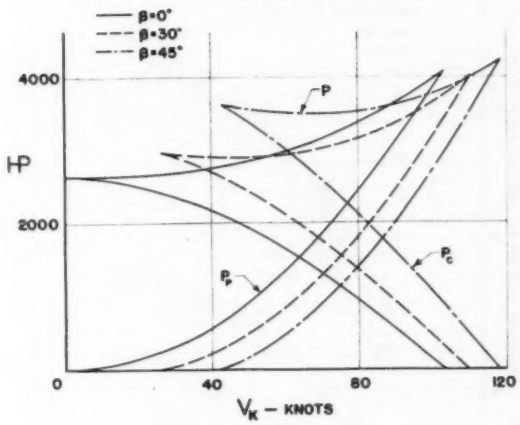


FIG. 11
EFFECT OF β ON POWER
V_K = 80
V_K = 90
V_K = 100
D_E = 50'
h = 2'
θ = -60°

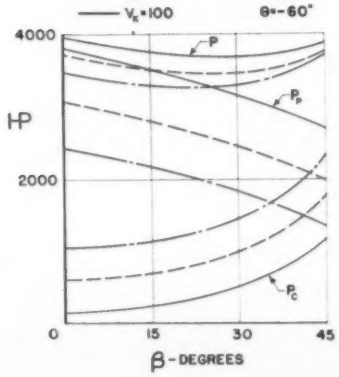
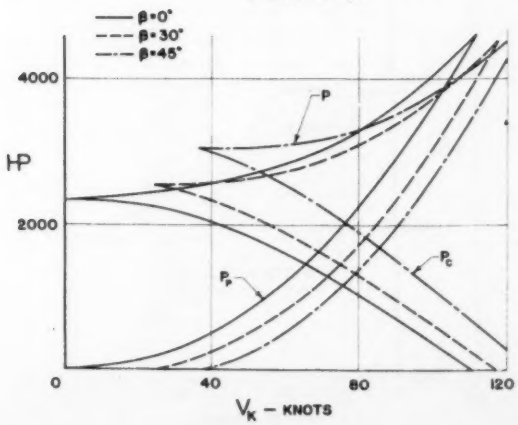


FIG. 12
POWER REQUIRED AT CONSTANT β
W_G = 90,000 LBS.
D_E = 50' h = 1'
G = 0.79' θ = -60°



A GEM FOR AMPHIBIOUS SUPPORT . . .

FIG. 13

EQUIVALENT LIFT-DRAG RATIO

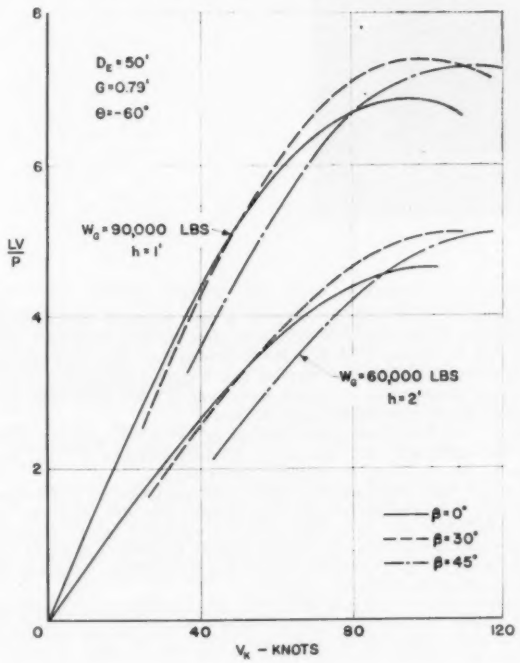
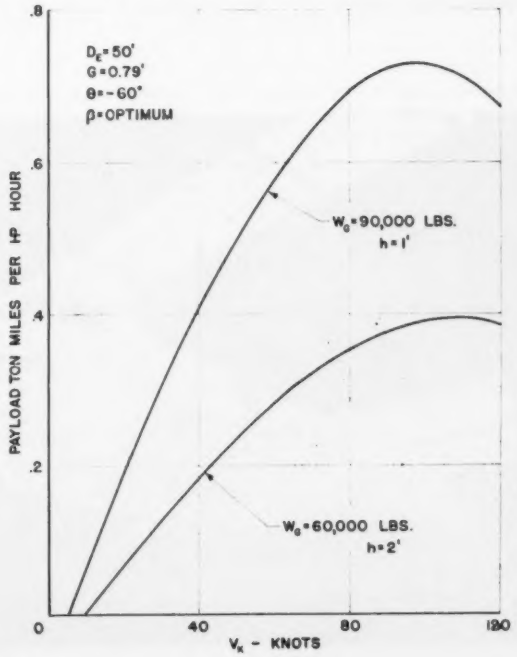


FIG. 14

ECONOMIC EFFICIENCY



CONSTRUCTION has started on a PT 50 hull in the foreground, while one adjacent to it is nearly completed. Nine PT 50s have already been delivered to operators and are in regular daily service.

MESSINA

MISCELLANY

Supramar's first licensee in Italy is the shipyard of Leopoldo Rodriquez, in Messina. The company built its first hydrofoil—the very first PT 20—in 1955, and the following year the craft started a regular service between Messina and Reggio (Calabria). In the first year of operation it carried more than 175,000 passengers and covered more than 60,000 nautical miles.

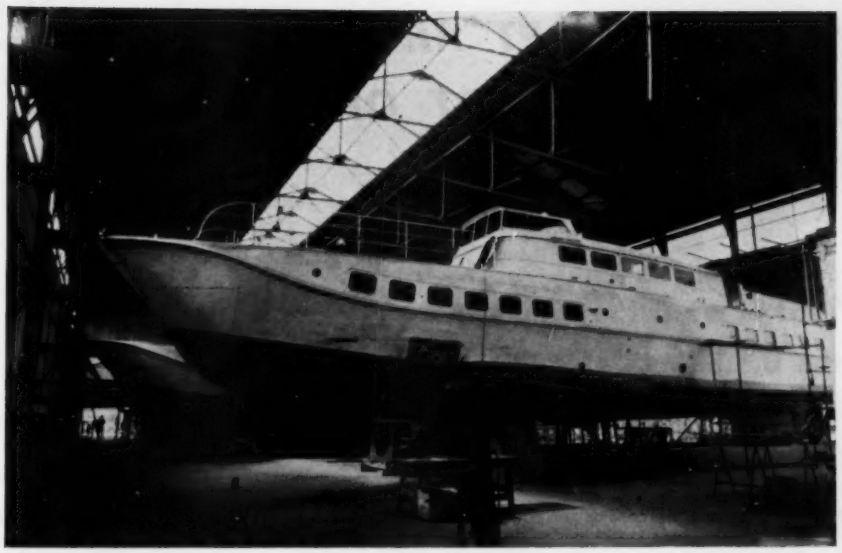
Since 1955 Rodriquez have built more hydrofoil craft for commercial operation than any other concern—fifteen PT 20s and nine PT 50s, delivered to thirteen operators.

Craft of both types are seen here under construction at Messina. They are built in four stages. First comes the hull, followed by the installation of the engines and the auxiliary power systems. Stage three is the fitting of the foil system, propellers and steering gear, the final stage covering the cabin furnishings, followed by the launching and running trials.

Hulls of the PT 20s are of a light alloy—Al Mg and Al Mg Si. Watertight compartments are provided below the passenger decks and in other parts of the hull, and a number of these are filled

COMPLETED HULL of a Rodriquez-built Supramar PT 20. Black circle is the attachment point for the forward foils. The bottom of the PT 20 hull has a step, which facilitates take-off and reduces resistance caused by wave crests.

GRACEFUL flowing lines of the PT 50 hull give it the appearance of being "in flight," even though it is still on the stocks.



with foam plastic, making the craft practically unsinkable.

Power for the PT 20 is provided by a Daimler-Benz MB 820 Db diesel marine engine of 1,350 h.p. There is also a 110 h.p. auxiliary engine in the stern for emergency operation. Driving a small separate propeller, this engine can be used to manoeuvre the boat in displacement condition.

The PT 20 is controlled entirely from the bridge which is located above the engine room. Forty-five passengers can be accommodated in the forward cabin, whilst the rear cabin is smaller and can take thirty passengers.

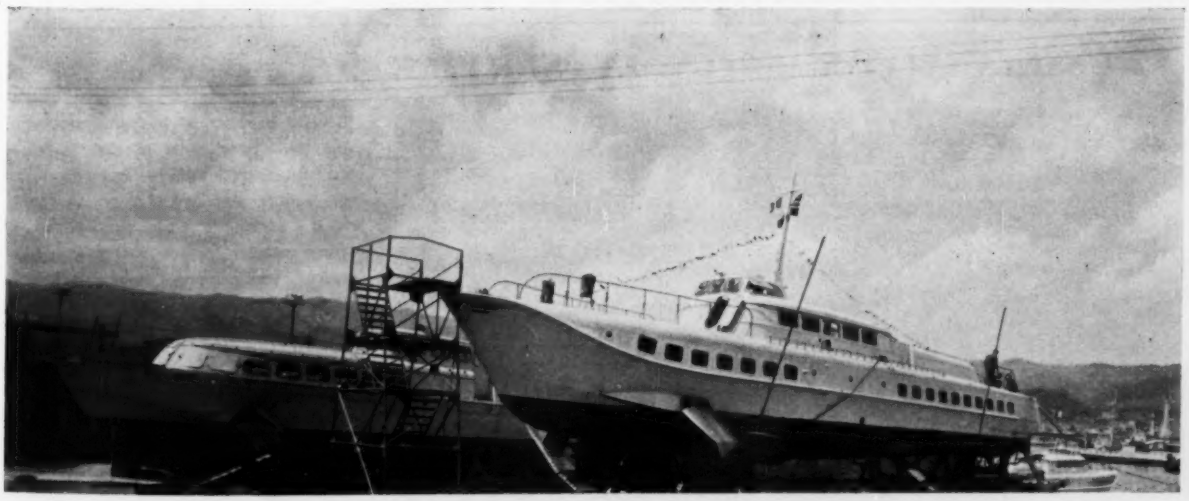
The prototype PT 50 was constructed at Messina in 1958. A larger and more powerful craft, it was designed for use farther away from the coast and for inter-island services. In the PT 50 passengers are placed below the main deck, which contributes considerably to the strength of the hull, allowing structural weight savings. Power is supplied by two of the same type of diesel engines fitted to the PT 20, which have been a great success. Shafting is simplified as compared with the smaller craft, by eliminating the V-drive. Both rear and forward foils are rigidly attached to the hull, but the lift of the forward foil can be modified by hydraulically-operated flaps.

Maintenance of these craft is undertaken at regular intervals of about 2–3 months. This includes the cleaning of the hull bottom and foils. In a tropical climate, where the intensified growth of barnacles affects the drag of the foils, more frequent inspection and cleaning is necessary. This work is usually undertaken by aqua-lung divers. Disregarding major machinery overhaul, which is normally due after 5,000 operating hours, the maintenance of the foils requires about 25 per cent of the maintenance work of the entire boat.

Strength and reliability of the foil system has been demonstrated several times when boats have run aground and have still been able to continue operation. A boat colliding with a pier caused considerable damage to the latter, while the craft suffered only minor deformations of the plating around the foil suspension point but was not forced to interrupt her service.

Both the PT 20 and the PT 50 have proved very profitable in areas with adequate passenger frequency. As with aircraft, the comparatively high speed of hydrofoil boats in relation to other waterborne craft results in a high earning power. Since the present foilborne craft usually operate at speeds up to three times that of other boats, their potential carrying capacity is up to three times greater. In other words, a hydrofoil can be considered equal in capacity to a ship up to three times its size.

SHIP SHAPE and ready for launching. In the foreground a PT 50, and at the side of it a PT 20. Both rear and forward foil of the PT 50 are rigidly attached to the hull, but the lift of the forward foil can be modified by the hydraulic operation of a flap.



"HOVERCRAFT ARE THE TRANSPORT OF THE FUTURE"

That is what they think in the U.S.S.R.

EVIDENCE THAT THE importance of hovercraft is fully appreciated in the Soviet Union is provided by a long article by V. Kozhokhin, Candidate in Technical Sciences, and I. Saltykov, engineer, published prominently in the daily newspaper *Pravda* on July 16th, 1961, under the headline "Transport of the Future."

Reminding us that the Soviet Union, for all its great industrial development, still remains a country where agriculture is of prime importance, the article starts off with a reference to the hard conditions with which agriculture must contend in the spring, which means roads, where they exist, being axle-deep in mud, rivers made unnavigable (and unfordable) by the ice broken up by the thaw, and much else of the kind. These are conditions which must be overcome successfully or the harvest will suffer, and to combat them there is need of a vehicle which is cheap, handy, simple, reliable, and reasonably fast, capable of working satisfactorily in conditions such as have just been described, and of traversing, where necessary, the snow-covered tundras and shifting sands, which occupy so great a part of the country—notably in the virgin lands recently put under the plough in Central Asia and Siberia.

Though it is only recently that the great potentialities of hovercraft for this purpose have been appreciated, the conception of such a vehicle dates back to the Russian better known for his pioneer work in rockets (of which the space-ships of Gagarin and Titov are the latest fruits), Konstantin Edouardovich Tsiolkovski, who is credited by the authors of the article with having written, at a date not mentioned, about the idea of having a vehicle supported by "a layer of air forced between its bottom and the ground beneath it." It is of more practical interest, however, to read that before the last war a team of young constructors, working under the direction of Professor V. Levkov, had already produced a vehicle which could move freely over ploughed fields, bogs and water, on a cushion of air, and that in 1940 the test pilot, I. Shelest, carried out successful tests of an aeroplane which had a cushion of air in place of the landing wheels. The war held up progress thereafter, until comparatively recently, when it was pushed ahead fast—and, it would seem, with some considerable success—possibly as the result of reported developments in this direction in other countries, notably in the United States and Britain, though Premier Khrushchov is reported to have been most impressed by some type of hovercraft, designed by a Hungarian engineer named Joszef Pal, which was on show at the Hungarian Exhibition in Moscow in 1960.

The authors envisage a wide range of hovercraft, ranging from vehicles capable of carrying loads of several hundred tons to single-seater equivalents of the motor-cycle, usable not only on the steppes of the European part of the Soviet Union and on the "virgin lands" already mentioned, but also, with slight modification, on the tundra and the deserts—wherever, in fact, there are large expanses of flat land. The greatest economic advantage is claimed, however, for those at the large end of the range, which obviates (in the Soviet Union) the heavy capital expense of building railroads, for which special roads with light surfacing would be a much cheaper substitute (where even these are required), and for which, of course, no bridges would be required for the crossing of rivers. Timber, now transported overland by heavily metalled roads or light railways, could be transported more easily and far more cheaply, wherever the country is flat, by hovercraft, for which the ground could be simply prepared by a grader.

Mention of the rivers moves the authors to recall that no country in the world is as rich as theirs in rivers, but that many

RUSSIAN HYDROFOILS IN SERVICE . . .

Several commercial hydrofoil motor ships have been built in the Soviet Union for operation on her many rivers lakes and canals. The Meteor, on the left is a 53-ton, 45 m.p.h. craft, with a seating capacity for 150 passengers. It features three passenger saloons a bar, awning promenade deck and air-conditioning. Two 850 h.p. diesel engines supply the power.

On the right is the earlier Raketa a 24-ton, 40 m.p.h. craft, which has a

"HOVERCRAFT ARE THE TRANSPORT OF THE FUTURE" . . .

of these are too shallow to be navigable, while the remainder are periodically made unnavigable by ice or broken ice, as mentioned earlier. Hovercraft can surmount the aforesaid obstacles to navigation, as can also, of course, hydrofoil vessels, but they have advantages over the latter in that they are not vulnerable, as are hydrofoil vessels, to damage by floating driftwood, etc., and that, where the bank is sufficiently low, they can go partly, or even wholly, ashore, for their loading and unloading, thus obviating the need for the construction of quays or piers. As regards speed, it is claimed that they can be fully competitive—the Central Office of Construction has recently published the details of a passenger-carrying hovercraft with a speed of 30 to 45 knots which is already being built, and faster ones are in project.

More extended maritime use of hovercraft is envisaged, especially for transport along the Northern Sea Route, round the north of Siberia, which links the European ports of the Soviet Union not only with those of its Far Eastern Territories (e.g. Vladivostok), but also with the ports at the mouths of the great rivers of Siberia, which are of fast-growing importance as the economy of that vast territory is developed, and as it is industrialised. Hovercraft with displacements of thousands and tens of thousands of tons could ply along that route (now open only for a comparatively short season, with the aid of ice-breaks like the powerful nuclear-powered *Lenin*) all the year round, moving with equal ease over water or ice, without the help of ice-breakers and with no risk of being frozen in for the winter.

Describing the advent of the hovercraft as a "qualitative" leap forward in transport, comparable with the railway in its time and, more recently, with the hydrofoil vessel and the jet aeroplane, the authors envisage possible useful extension of the "principle" in connection with all kinds of machinery. They warn, however, against "the doubts" of short-sighted critics on the one hand, and on the other against ill-informed "enthusiasts," such as one whom they quote as having written recently in the magazine *Znaniye-Sila* ("Knowledge is Power") claiming that hovercraft can "jump over obstacles"—they can never aspire to compete with the vertical take-off aircraft, remark these more practical authors; they have quite enough to do at ground level.

The main advantage of the hovercraft, they point out, is that it has no direct contact with the ground or water, but this gives rise to problems to which we must not shut our eyes. Among these are problems in relation to stability and manoeuvrability, which have yet to be solved completely. Others arise from the fact that the air blast beneath them raises clouds of dust or spray, as the case may be, but these have been overcome. They warn their Soviet designers, now hard at work on the development of hovercraft of various types, that it is most important that they should decide *beforehand* very definitely the purpose for which the hovercraft which they are designing is intended: a special type should be developed for each of the various conditions in which it will be required to operate, e.g. for use over the "virgin lands," over ice, or along small rivers. They must follow developments abroad very keenly, but critically, for though hundreds of types are being developed there, "many of these are being built solely for purposes of publicity—to provide cheap sensation." It is most important, moreover, that there should be a large co-ordinating centre for the co-ordination of all research and development in this fascinating and important new field.

"Hovercraft are indeed the transport of the future," they write in conclusion, "but a great deal of real hard work is called for to make that future come as soon as possible."

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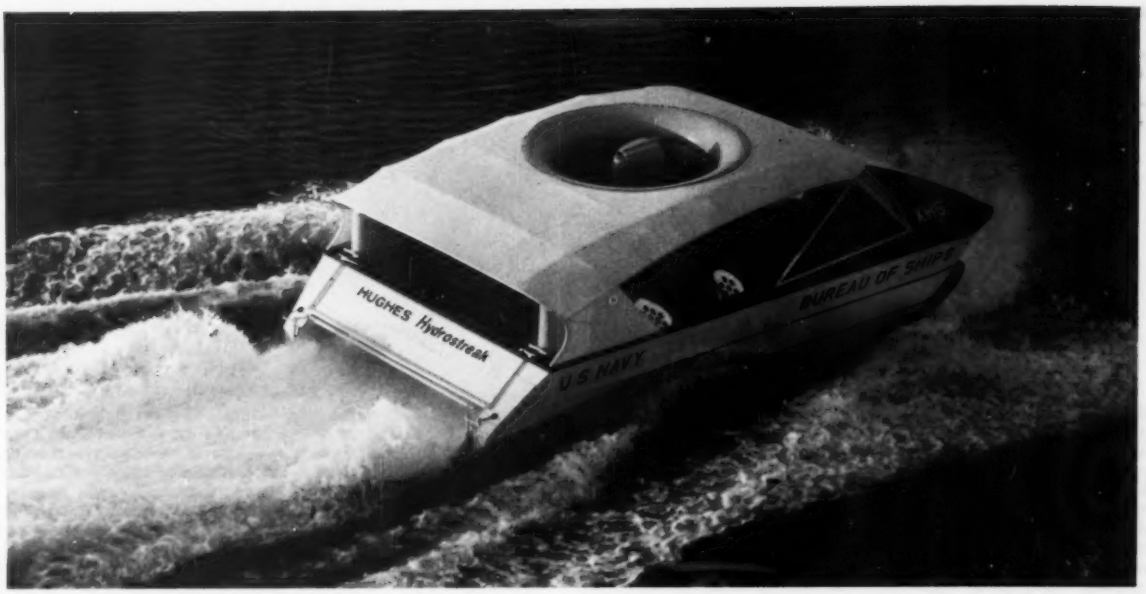
seating capacity for 66. The hull is of aluminium alloy and power is provided by a 900 h.p. diesel engine.

The Russian Ministry for the River Fleet has announced plans to build 200 Raketas and 85 Meteors. Sixty Raketas are reported in operation, but this is unconfirmed. Both these craft, and the new 300-seat Sputnik, have been designed by Rostilav Alexeyev. They are built in the Red Sormovo shipyards on the Volga, near Gorky. The Raketa was launched in 1959, the Meteor in 1960 and the Sputnik in 1961. Bigger craft, including ocean-going types, are now under construction.

(Photos by courtesy of Soviet Weekly).



HYDROSTREAK version seen above employs only two water-walls, one fore and one aft, with solid fins or "skegs" on the sides. It rises about two feet and power for its fan, pumps and propellers is supplied by three 80 h.p. engines.

HUGHES HYDROSTREAK WATER-WALL CONCEPT

THE HUGHES HYDROSTREAK is based on an entirely new technological concept—the "water-wall." This is a thin sheet of water used to contain a high-pressure "bubble" of air under a vehicle, and upon which bubble the vehicle is supported. The concept was invented and developed as a proprietary item in 1959.

The much greater density of water results in a large increase in efficiency. The associated power savings, plus the greatly reduced bulk and mass of power plant, pumping equipment, and ducting constitute the major advantages of the water-wall.

The first application of this principle is the 21-foot craft illustrated. It has solid side walls and fore-and-aft water-walls. It is given its forward motion by the water being discharged at an angle and by conventional propellers extending into the sea.

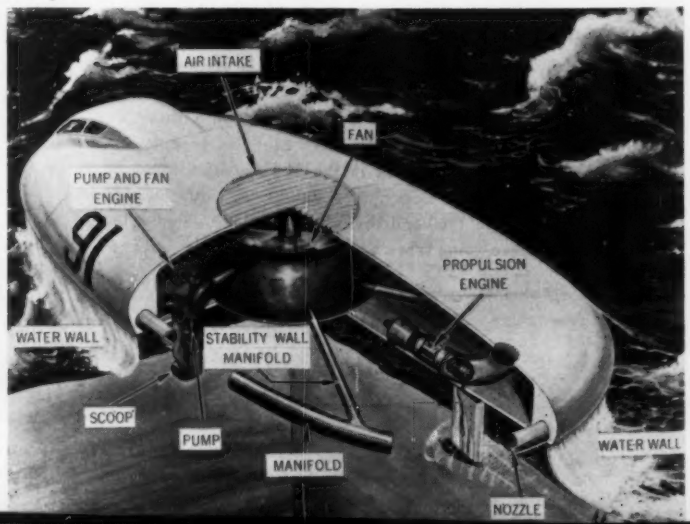
Operation of the Hydrostreak vehicle can be explained as follows:

Air is taken in at the top of the vehicle, compressed by a fan and exhausted under the vehicle to form the air cushion. Water is taken on board through scoops and pumped into a peripheral manifold. Nozzles produce a thin, continuous sheet of water to form the water-walls which contain the air bubble. Pumping and fan power are supplied by an engine and transmission system which usually will be separate from the propulsion system. Stability in roll and pitch can be controlled by compartments formed by radial water-walls.

The theoretical superiority of the water-wall vehicle over its air-wall counterpart is based on a simple physical fact: sea water is 840 times as dense as air. The total pressure of either the water-wall or the air-wall must be significantly higher than the pressure of the air it contains. Because of the much heavier density of water, the velocity required by the water-wall is theoretically $1/\sqrt{840}$ or 1/29 the velocity required if an air-wall were used. The lifting efficiency of air- or water-wall vehicles is inversely proportional to the velocity used, so that very high efficiencies can be obtained with the water-wall.

Hughes engineers already have evaluated a large number of nozzle and manifold designs and have made significant findings in this new field. An extensive literature search has revealed no prior art in this field, though very interesting work has been done in England on low-speed fluid films for different applications.

Intensive laboratory research is continuing under U.S. Bureau of Ship sponsorship, and design data for large air-supported craft is being obtained.



CUTAWAY of a hypothetical ocean-going craft with a peripheral water-wall, showing how such a craft would operate.

HOVERCRAFT NETWORK PLANNED

DETAILS OF AN application by Starways Ltd., the Liverpool Airline, to operate a network of hovercraft services have now been accepted by the Air Transport Licensing Board. While there is no indication as to the date of the hearing, the company has asked the Board to give an early decision to the application in view of the long-term planning and development necessary on the routes envisaged.

It is anticipated that the initial development programme for the craft chosen will be undertaken close to Starway's base at Liverpool Airport, which has a frontage on the River Mersey. A crossing problem of the Mersey already exists at Speke, caused by tidal activity and the heavy volume of traffic and passengers, which cannot always be accommodated by the Mersey Tunnel.

The company envisages the craft being used for the carriage of passengers, vehicles and freight, and although they have not yet decided on the particular craft to be used, they are thinking of initially operating one in the region of 25 tons. Their long-term plans are based on one capable of lifting a 50 ton load and with an all-up-weight of about 120 tons. They feel this size of craft is necessary so that operating costs can be brought down to an economic level, thus giving competitive fares on all the routes in question. Indications show that with the larger types, fares can be introduced which will be very attractive to the public. They may be as low as 1d. per passenger mile.

The date on which operations will commence is dependent upon three factors: the date of decision by the Board; the time taken by Starway's development programme, and lastly the training period required for familiarisation to the craft.

The craft would be maintained initially at the company's overhaul base at Speke Airport, Liverpool, with a secondary base at Glasgow and subsequently bases would be provided as necessary in other parts of the country.

Mr. J. A. Wilson, Starway's director in charge of this project, had these comments to make to HOVERING CRAFT AND HYDROFOIL recently:

"My company feels that the benefits of hovercraft in England will be felt mainly in the areas between the mainland and the islands, and across the water stretches, i.e. mouths of the major rivers. It will provide speedy transportation over medium stage lengths where the aircraft is not suitable and where normal shipping is too slow.

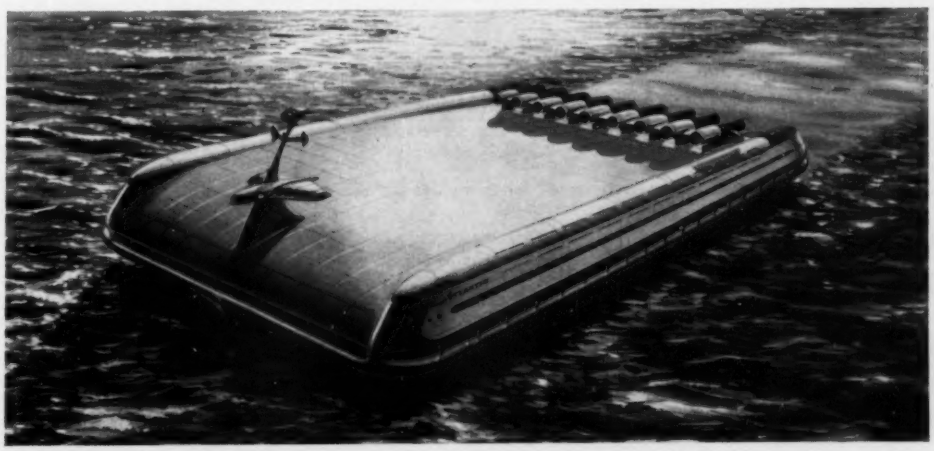
"It should be emphasised that the speed of these craft will be three or four times greater than that of normal shipping and, up to a certain stage length, they will be quicker than conventional aircraft.

"I am doubtful if there will be anything available for at least twelve months in the form of a public transport service. The larger hovercraft, which are obviously going to take longer to produce more than the initial models, will be more suitable for the work this company has in mind. It is in respect of these larger hovercraft, carrying about 200 to 500 passengers together with cars, that we are mainly interested.

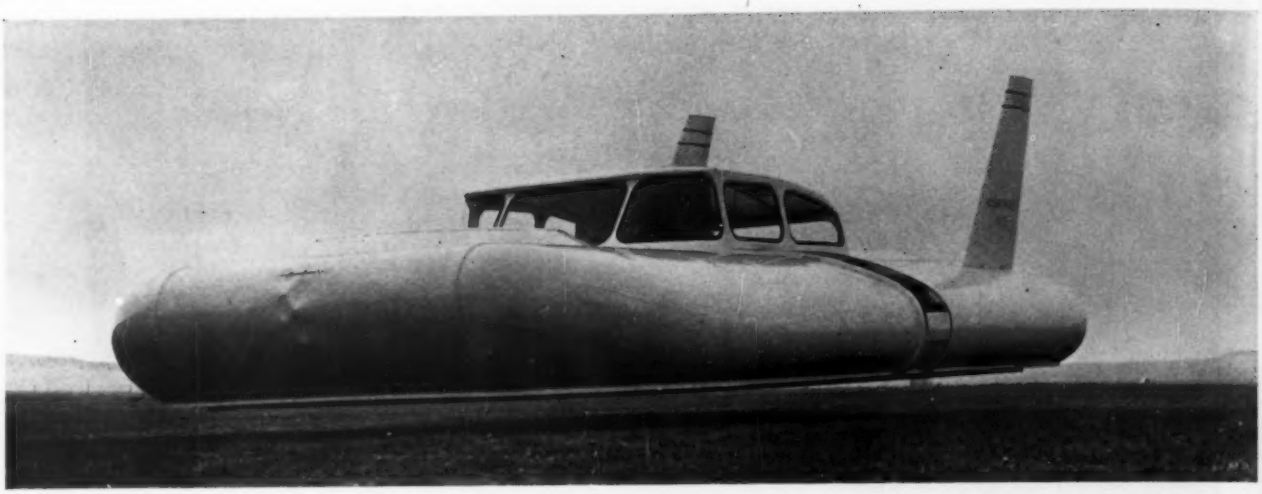
"The craft should appeal to a large section of the public who previously have been somewhat afraid to travel by airplane, and who find on the other hand that ships are extremely slow. In this instance, the hovercraft can be regarded as complying with their wishes in respect of speed and safety."

Starways have applied to the Air Transport Licensing Board to operate on the following routes:

Between any two places situated on the north and south side of the River Mersey; any two places situated on the north and south side of the River Thames including Canvey Island; between any two places situated on the north and south side of the River Severn and Bristol Channel; Liverpool and the Isle of Man; Dover and Calais; London and Calais; Liverpool and Belfast; Portsmouth and/or Bournemouth and/or Southampton and the Isle of Wight; Plymouth and/or Southampton and Jersey and/or Guernsey; Scilly Isles and Newquay and/or Penzance; Harwich and Rotterdam and/or Antwerp; Liverpool and/or Holyhead and Dublin; Glasgow and/or Stranraer and Belfast.



TRANS-ATLANTIC air cushion craft; this futuristic concept by Bell Aerosystems would have sufficient height to be unaffected by waves.



The new CC-2 after its first "lift-off" at Bembridge, Isle of Wight.

Rolls-Powered Cushioncraft

BRITTEN-NORMAN, of Bembridge Airport, Isle of Wight, was one of the first firms in the United Kingdom to construct a ground effect machine. Their first venture, the experimental CC (for Cushioncraft)-1, made its appearance in June 1960. Circular in shape, it employed a peripheral rotor for lift, and had two outrigged airscrews for forward propulsion and control.

While the CC-1 was intended to examine the possibilities of freight carrying—it was commissioned by Elders and Fyffes as a prototype banana ferry boat—the new CC-2, which made its first lift-off in early September, is intended for passenger services. It is an intermediate-size craft, built in response to requests from many potential operators who want a relatively cheap, completely amphibious machine for route trials, and also to gain light hovercraft experience before they are prepared to commit themselves to bigger and more expensive machines.

Seating ten, and powered by a Rolls-Royce V-8 petrol engine supplied by Rolls-Royce especially for this craft, the CC-2 will sell at "well under £20,000." At this price it is felt it will be within the reach of many companies around the world not necessarily connected with commercial transportation but which believe they can usefully employ air cushion vehicles.

On the basis of tests already completed, the company is confident that clearance heights approaching two feet are within reach of the CC-2 and forward speeds of up to 50 m.p.h. are predicted.

The craft is propelled and steered by thrust from the air curtain jets and no external propellers are used.

GENERAL DESCRIPTION

A general purpose vehicle, the CC-2 gives a useful performance with a standard production automobile type engine. The structure is so arranged that the craft may be dismantled into three sections to simplify transportation and packing.

Lightly laden it will attain clearance heights of the order of two feet, which in combination with its modest size, will permit operation upon quite severe gradients or very rough surfaces. When maximum ground clearance is not the major performance criterion, loads exceeding the tare weight of the craft may be transported.

A wide performance range is attained by careful fan design combined with a light structure weight. Aerodynamic efficiency is achieved because the low air velocities used reduce the energy losses between the fan and the peripheral jet. This approach to overall efficiency is believed to be simpler and lighter than the use of a recirculation system. Structure weight is kept to a minimum through the use of thin gauge light alloy panels, supported by lightweight plastic foam. The foam core of the basic structure prevents the flotation hull becoming waterlogged if the bottom skin is damaged.

The aerodynamic design permits a sizeable increase in horsepower with a proportional increase in performance without need for structural modification.

A cab approximately 9ft. x 8ft. is provided. The engine box is located in the centre of the cab floor and a trunk carries away engine cooling air and houses the exhaust piping. Adequate

We are delighted to see the publication of a specialist journal covering air cushion vehicles. These craft are still at an early stage and their role in the future pattern of world transport is still to be defined. Your journal can be valuable both as a forum for discussion and as a means of publicising not only achievements but also the many operational problems that must be expected.

We send you our very best wishes for your venture.

F. R. J. BRITTEN,
N. D. NORMAN.

Rolls-Powered Cushioncraft . . .

transparencies are provided for all-round vision. A laminated glass windscreen and high speed wipers are standard.

There is a permanent bench seat in front of the engine box for the driver and one passenger. Space is available for seating to accommodate eight additional passengers. The cab is sealed and pressurised to a differential of 5 inches of water to eliminate dust and fumes. The cab which has a total usable volume of approximately 300 cubic feet may be furnished and equipped to customers requirements.

The CC-2 uses a simple integrated propulsion system. Jet thrust is supplemented by pitching the craft in the direction of travel.

Pitch control is obtained by the operation of flaps in the front and rear peripheral jet nozzle area. Roll control is obtained in the same way by the operation of flaps in the peripheral jet on either side of the craft. Control in yaw is obtained by differential operation of moveable vanes located in the stability jets.

Water ballast up to 100 lb. in weight may be transferred between ballast tanks located at the extreme ends of the buoyancy chamber for trimming in pitch and fuel may be distributed between side mounted tanks to provide trim in roll.

Right and left hand whipstaves swing fore and aft to operate the propulsion controls and swing outward to control the appropriate roll flap. Differential fore and aft movement of the whipstaves gives directional control. A pair of foot controls similar in style to automobile throttle and brake pedals provide bow down and stern down pitch. A hand throttle is fitted and full automobile engine instrumentation is provided.

CC-2 DATA

Leading Particulars

Length: 27ft.
Beam: 17ft. 1in.
Height to top of fin: 8ft. 6in.
Dry weight: 3,100 lb.
Engine: Rolls-Royce L.V.8.
Type: 8-cylinder over-square 90° V formation; liquid cooled.
Capacity: 380.2 cu. in. (6,230 c.c.).
Fuel: Petrol (car grade).

Performance

Normal all-up weight: 5,500 lb.
All-up weight with overload: 7,000 lb.
Fuel capacity: 120 gallons.
Max. range at normal all-up weight: 500 miles.
Hoverheight at normal all-up weight: 12 inches.
Hoverheight empty: 24 inches.
Max. speed at normal all-up weight: 55 m.p.h.

ONE OF THE MOST ELEGANT of the present generation of GEMs, the CC-2, is seen here in its hangar at Bembridge.

News in brief . . .

Second British company to declare its intention to operate overwater air cushion vehicle services is P. and A. Campbell, the Cardiff shipping firm. The directors plan to run a number of 200-passenger craft across the Bristol Channel. The company at present operates passenger steamers from Cardiff to Weston-super-Mare and Minehead. Campbell has notified the Air Transport Licensing Board that they would like to operate air cushion craft to and from all Bristol Channel ports.

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The U.S. Navy feels that ideally the GEM for assault use should be flat on top and bottom, even practically square or rectangular, so as to permit stacking in tiers. But if the GEM is to be flat for stacking, what about its "office" for operator vision, or power plant, or exterior controls that normally protrude from the top or sides? Must these items be retractable for shipment, thus complicating the GEM's construction? According to the U.S. *Naval Aviation News*, one snappy solution offered by a U.S. firm is an inflatable assault GEM.

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Design studies for military hydrofoils by Hispano-Suiza have led to the introduction of two new variants of the Supramar PT.20 and PT.50, designated respectively the PAT/20 and PAT/50. Advantages given for the hydrofoil patrol craft include the following: Because of their low draught they pass over anchored mines without causing them to explode; since they do not cause magnetic variations (their hulls are in light aluminium non-metallic alloy) they can pass over magnetic minefields without danger; also, as they do not cause pressure waves, they will not explode pressure mines. If hit by machine-gun fire they can continue their run as the hull is completely above the waves and the holes produced could not cause any water penetration. Finally, hydrofoils cannot capsize. The metacentric height of their hulls is a considerable improvement on that of traditional hulls of equal displacement.

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One of the growing number of companies in the United States conducting research in the field of ground effect machines is the Hiller Aircraft Corporation. One of their programmes involves the investigation of thrust augmentation, and another involves the evaluation of two special configurations which have excellent potential for economical high-speed forward flight. These configurations are the diffuser-recirculation and the diffuser-plenum. Hillers have recently concluded a report which recommends further study of these configurations.

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According to an American report, the Bureau of Ships is to build a 50-foot test craft shortly and a 150-foot ocean-going craft for experiments and evaluation in anti-submarine warning (ASW) and amphibious work in 1963.

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Ground effect machines that extend deep into the domain of the aircraft are a distinct possibility. They would be limited to ground effect only for take-offs and landings. After take-off the machine would assume free flight just like a conventional aircraft. At this stage, however, aviators feel that the craft is no longer a GEM. They say the craft could be called a VTOL or STOL, but the terms would be wrong. Such a vehicle would be a GETOL—ground effect take-off and landing craft.

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First plan to be announced for a hydrofoil service between the European continent and the British Isles comes from a former Commander of the Netherlands Navy—Commander Matthys Bos, with headquarters in the Hague. He plans to operate 400-passenger Aquavion hydrofoils between the Hook of Holland and Harwich. His company announces that the cost of the craft, which will be capable of 40 knots, will be only £600,000, compared with £2 million for a comparable displacement craft. Journey duration between the Hook and Harwich would be 2¼ hours instead of more than six hours. The Commander says he has much bigger craft in the project stage.

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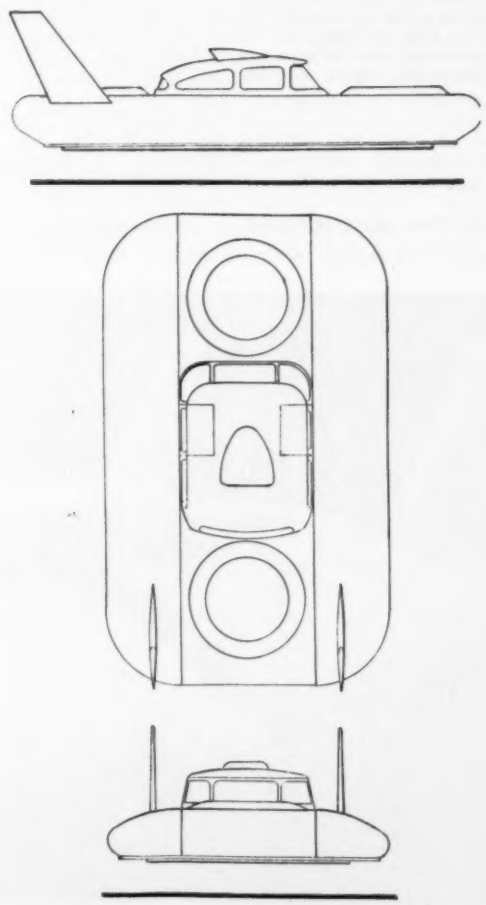
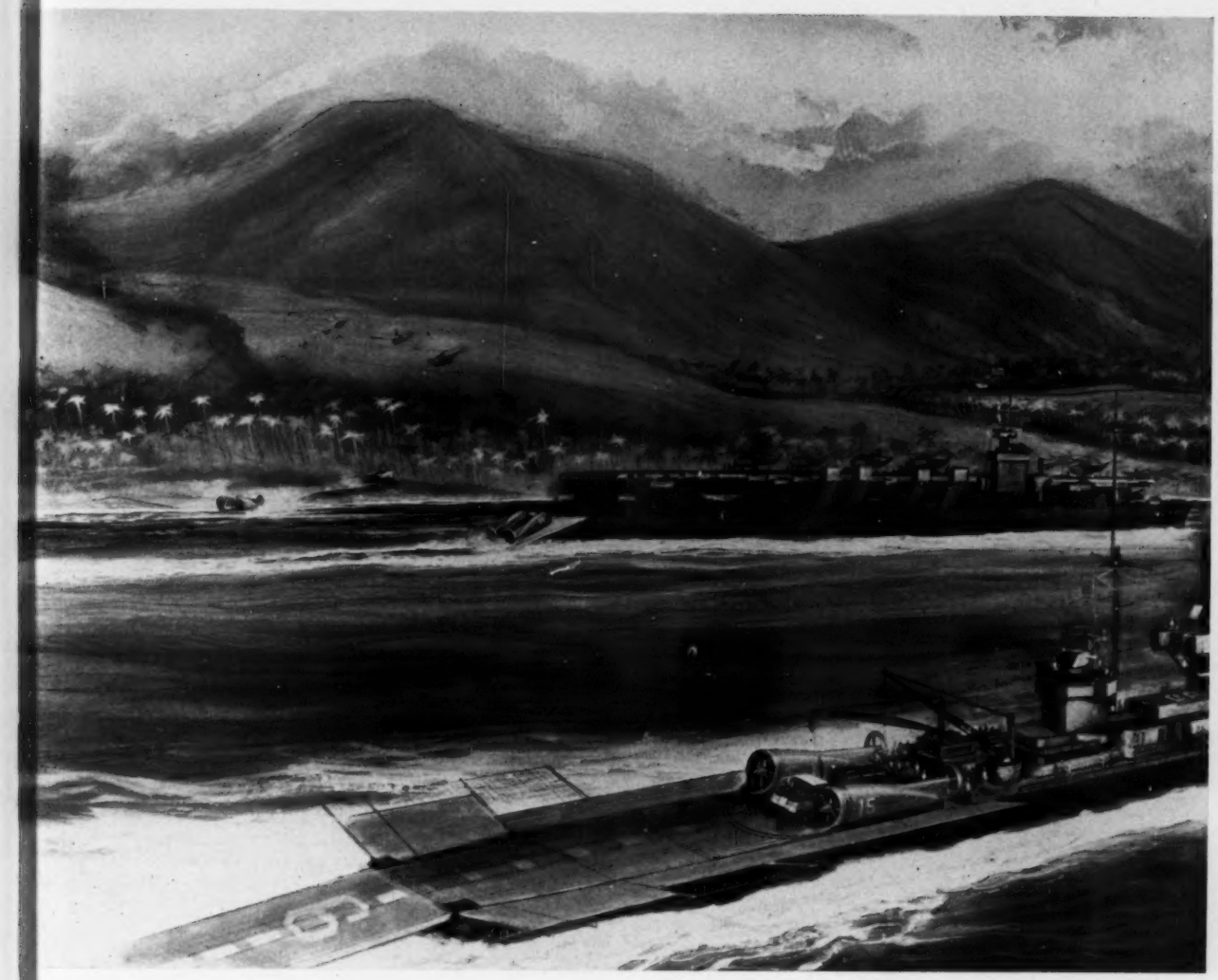
THREE-VIEW DRAWING of the new Britten-Norman CC-2 Cushioncraft.





This is a utility vehicle capable of providing air-cushion capability at every echelon on the battlefield. It is a design study concept by the Aeronutronic Division of the Ford Motor Company, prepared for the U.S. Army Transportation Research Command. Using an annular jet type air cushion, it is powered by two 300 h.p. engines, one of which is mounted at the rear of each of the two outer panels. Each engine drives a reversible-pitch pusher propeller for propulsion, yaw control and braking, and a forward mounted fan (through a shaft) which provides air for the annular jet. The air pump fans force air into the large ducts which distribute the air to the peripheral jet. The fans are of variable pitch and when controlled differentially, provide varying quantities of air for their respective half of the peripheral jet to give positive roll control. It has a clearance height of 5 feet, which is considerably in excess of ground clearances of present Army surface equipment. It is believed that air-cushion vehicles with this clearance capability will be able to negotiate nearly all off-road obstacles, and provide a significant increase in current off-road capability. Payload 2½ tons; speed, 40 m.p.h.; ground clearance, 5 feet; range, 100 miles; grade capability, 30% (17°). Dimensions: 8,000 pound gross weight. Rectangular planform 24 feet wide and 38.5 feet in overall length. Central load carrying platform is 8 feet wide and 24 feet long.